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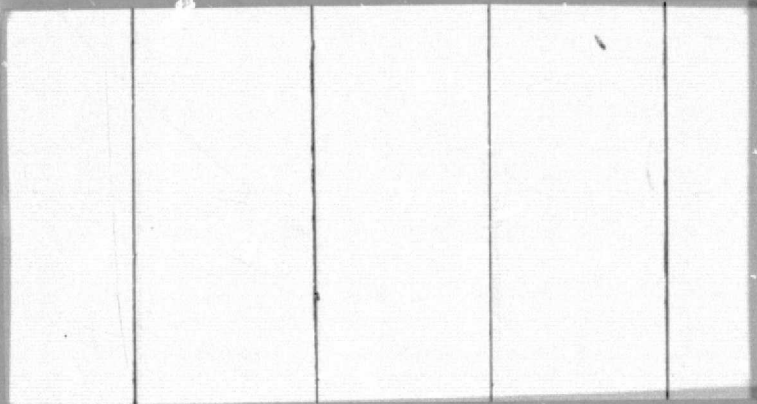
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**DRAFT**

SEASAT-A CANDIDATE OCEAN  
INDUSTRY ECONOMIC VERIFICATION  
EXPERIMENTS

Prepared for

Special Programs Division  
Office of Applications  
National Aeronautics and Space Administration

Contract NASW 2558

September 16, 1976

## NOTE OF TRANSMITTAL

This study of SEASAT-A candidate ocean industry economic verification experiments was performed for the Special Programs Division, Office of Applications, National Aeronautics and Space Administration, under contract NASW 2558.

The study of the candidate economic verification experiments was performed by a team consisting of the Battelle Memorial Institute, ECON, Inc., and the Jet Propulsion Laboratory (JPL). The chapter on Innovation and the Technology Transfer Process, and the section on Applications to the Offshore Industry, were provided by Battelle. ECON prepared the sections on An Ocean Routing Experiment, A Ship Routing Experiment in the Belle Isle Straits, and Coastal Zone Applications. JPL prepared the sections on the Applications to the Ocean Fishing Industry, Ice Monitoring Applications, Other Experiments, and A Tanker Routing Experiment in the Aghulas Current. The Battelle effort was directed by Dr. Alfred C. Robinson, and the JPL work was managed by Mr. Allen P. Bowman. The Ocean Routing Experiment was prepared by Dr. William Steele of ECON. Mr. Russell Barton of ECON performed the work on the Ship Routing Experiment in the Belle Isle Straits, and the work on Coastal Zone Applications was performed by Mr. Kenneth Hicks of ECON.

In addition to the above, I wish to express my gratitude to Dr. Vincent Cardone of CUNY, and Mr. S. W. McCandless of NASA, the SEASAT-A Program Manager, for their assistance in this study of SEASAT-A candidate economic verification experiments.

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B.P. Miller

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## 1. SUMMARY

During 1974-75, an economic assessment was performed to estimate the economic benefits of an operational SEASAT system. The economic assessment indicated substantial economic benefits, in excess of program costs, in the areas of marine transportation, offshore oil and natural gas exploration and development, ocean fishing, and Arctic operations. With the launch of SEASAT-A in 1978, the opportunity will exist to obtain experimental data on the economic performance of this ocean observation system. In 1976 preliminary studies were completed to define experiments which could be performed with SEASAT-A to demonstrate the scientific and economic features of the system. In the economic area, the purpose of these experiments is to provide data to help design the characteristics of follow-on SEASATs to meet civilian sector or commercial user economic needs.

This report provides a description of the candidate economic verification experiments which could be performed with SEASAT-A that have been identified in studies performed to date. With the exception of the area of Arctic operations, experiments have been identified in each of the areas of ocean based activity that are expected to show an economic impact from the use of operational SEASAT data. Experiments have been identified in the areas of the offshore oil and natural gas industry, as well as ice monitoring and coastal zone applications. Emphasis has been placed on the identification and the development of those experiments which meet criteria for:

- End user participation
- SEASAT-A data utility
- Measurability of operational parameters to demonstrate economic effect

- Non-proprietary nature of results.

Because of limitations of time and resources, not all of the candidate economic verification experiments have been developed to the same level of detail. It is hoped that a number of candidate experiments dealing with Arctic Operations can be developed in the future with the cooperation of the Canada Centre for Remote Sensing, and that the level of detail for many of the candidate experiments can be increased to provide the basis for selection by NASA.

## 2. INTRODUCTION

The SEASAT Economic Assessment, completed in 1975, identified the fact that substantial, firm benefits from the use of operational SEASAT data can be obtained in areas that are extensions of current operations, such as marine transportation and offshore oil, and natural gas exploration and development. In addition, it was concluded that very large potential benefits from the use of SEASAT data are possible in an area of operations that is now in the planning or conceptual stage, namely, the transportation of oil, natural gas, and other resources by surface ship in the Arctic regions. A further area of large potential benefits that was identified stems from the use of SEASAT data in support of ocean fishing operations. Table 2.1 presents a summary of the major benefit areas attributable to the use of operational SEASAT data. For the sake of clarity, several smaller benefit areas have been omitted from this table. The interested reader is referred to the SEASAT Economic Assessment for a complete discussion of the case studies, their generalizations, and the estimation of the benefits.\* For the purpose of the economic assessment, the operational SEASAT system was considered to begin in 1985. The economic benefits shown in Table 2.1 begin in 1985 and are accrued in the period from 1985 through 2000. The range of benefits estimated reflects present uncertainties in the future development of the areas studied, as well as uncertainties in the expected performance of the operational SEASAT system. All benefits are stated in \$1975, at a 10 percent rate of discount.

The benefit estimates made in the SEASAT Economic Assessment are largely based upon empirical evidence and best estimates of the expected impact of

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\* SEASAT Economic Assessment, ECON, Inc., 31 August 1975.

Table 2.1 SEASAT Major Benefit Areas\*

Area	Integrated Benefit (\$Millions, 1975)
Arctic Operations	96-288
Coastal Zones	3- 81
Marine Transportation	215-525
Ocean Fishing	274-1432
Offshore Oil & Natural Gas	214-344

\* Benefits attributable to an operational SEASAT system, 1985-2000, at 10% discount rate.

operational SEASAT data on operations in the areas of maritime activity considered in the assessment. The launch of SEASAT-A in 1978 will provide the first opportunity to obtain experimental evidence of the effects of SEASAT data on the economic performance of selected areas of maritime activity.

Through the use of SEASAT-A data in a series of designed experiments, it should be possible to obtain information which will be useful in guiding the design of future oceanographic satellite systems to emphasize those characteristics that are of economic importance to civilian sector and commercial users. A secondary purpose of these experiments could be to begin the process of the transfer of the technology of the SEASAT system from NASA to the expected users of an operational SEASAT system.

This report describes a number of potential economic verification experiments that could be performed using SEASAT-A. The purpose of these experiments is to provide data to design follow-on SEASATs to meet user economic needs. A large number of potential economic verification experiments were considered in this study, and because of limitations of time and resources not all of the potential experiments have been developed to the same level of detail. The absence (or presence) of detail at this time does not imply a prioritization or recommendation of specific experiments. It is hoped that the participants in this study will have further opportunity to develop additional information on many of the potential experiments that could only be described in a very preliminary manner for this report.

Four criteria were applied to the selection of the proposed economic verification experiments, as follows:

1. Is there industry interest in the experiment?  
Since the experiments are intended to obtain data to help design future oceanographic satellites to meet the economic needs of civilian sector (commercial) users, it is important to obtain the cooperation and/or participation of the user concerned in the performance of the experiment.
2. Can the experiment be supported with SEASAT-A data?  
Since SEASAT-A is not an operational system there will be system constraints on the collection, processing, and distribution of the SEASAT-A data. Thus, a determination that SEASAT-A can provide data needed to support the experiment is a necessary criteria.
3. Is it a measurable experiment? In order to estimate economic impact it is necessary to be able to measure the operational characteristics of the systems involved. For example, in a ship routing experiment it is necessary to measure the transit time, fuel consumed, and losses incurred for a large number of vessels. In each experiment it is necessary that similar measurable operational parameters can be identified.
4. Can the results of the experiment be made available to the general body of interested users? It is conceivable that some experiments could produce results that are of proprietary importance to a single commercial user. Given that the purposes of the SEASAT-A experiments are to provide guidance to the characteristics of future systems and to begin the process of the transfer of SEASAT technology to users, it is important that the results of the experiments can be made available to all interested parties.

Although the above four criteria were applied to the selection of all of the proposed experiments, it must be realized that much further work remains to be done to make certain that these criteria can be fully satisfied before the final recommendation can be made for experiments to be implemented by NASA.

An important consideration in the development and selection of the economic verification experiments is the ability of SEASAT-A to produce now-

casts of ocean parameters such as ice, waves, and winds, as well as to produce data for use in forecasts of weather and ocean conditions. Experiments which use both the nowcast and forecast capabilities of the SEASAT-A data are contained in the candidate economic verification experiments. A further consideration is that some of the experiments involve the measurement of phenomena which may occur only a few times during the expected life of SEASAT-A. Other candidate experiments are statistical in nature, involving many measurements, over an extended period of time, with both an experiment and control group of test subjects. Although estimates have not been made of the costs of implementing these experiments, it is believed that in general the statistical experiments will require more time to perform and will be more costly than those experiments which deal with either unique events or events which occur seasonally.

The following sections of this report provide descriptions of the candidate economic verification experiments.

### 3. INNOVATION AND THE TECHNOLOGY TRANSFER PROCESS

The SEASAT-A system will provide types and amounts of data for the world's oceans which have not been hitherto available. NASA is concerned not only with ascertaining that these data are applied to yield new scientific results, but also with assuring that the widest possible use is made of this unique technological capability by the industrial sector. These data will permit industrial or commercial organizations to do things which were not possible before, or to accomplish existing operations in a more complete or less expensive way. Accordingly, it is of interest to consider the process by which new technology is applied to commercial or economic activities.

This process has been extensively studied during the past 15 years, and the results of this work can provide useful background for anyone concerned with the problem of fostering the use of SEASAT data by industry. Over 3000 papers have been published dealing with one part or another of the innovation process and more than a dozen books have appeared. There is currently a new technical society, The Technology Transfer Society, devoted to the study of the innovation process itself. A number of federal organizations, including NASA, are undertaking new initiatives in technology transfer. Also, the Congress has considered and is considering various measures for enhancing the transfer of existing federal technology. The Science and Technology Act of 1975 authorized the creation of a Technology Transfer Office at the White House level. This has not as yet been implemented but is currently under discussion.



It seems clear that the importance of the technology transfer problem is becoming more widely recognized and the mechanisms are being studied more carefully.

The general nature of the innovation process is indicated in Figure 3.1. Chronologically, the process starts with a conception or an invention. This is a bringing together of a technological capability with a perceived need or problem area. The concept is then evaluated in the light of market needs, and if it appears to be promising then an investment may be made to verify the concept by a working model or small-scale trial. The results of this are again evaluated, and if they appear to be promising, a development may be undertaken to create a product suitable for wide-scale use. If this development program is successful, the product may be produced or the concept otherwise implemented. At this point there is a marketable product or process and the problem then is one of getting it used. If the product is successful, in that it is widely adopted, there may follow another phase in which society adapts itself to the availability of the new product. Reorientation of U.S. housing patterns as a result of the availability of the automobile is an example of this sort of adaptation. This final phase, however, is not indicated in Figure 3.1. The entire development process is motivated and controlled by perceived market needs. This perception has frequently proved to be erroneous but it none the less must be viewed as a major underlying consideration.

The individual steps shown in Figure 3.1 will be discussed in more detail in later subsections, but before proceeding with this, some general observations can be made about the process as a whole. The

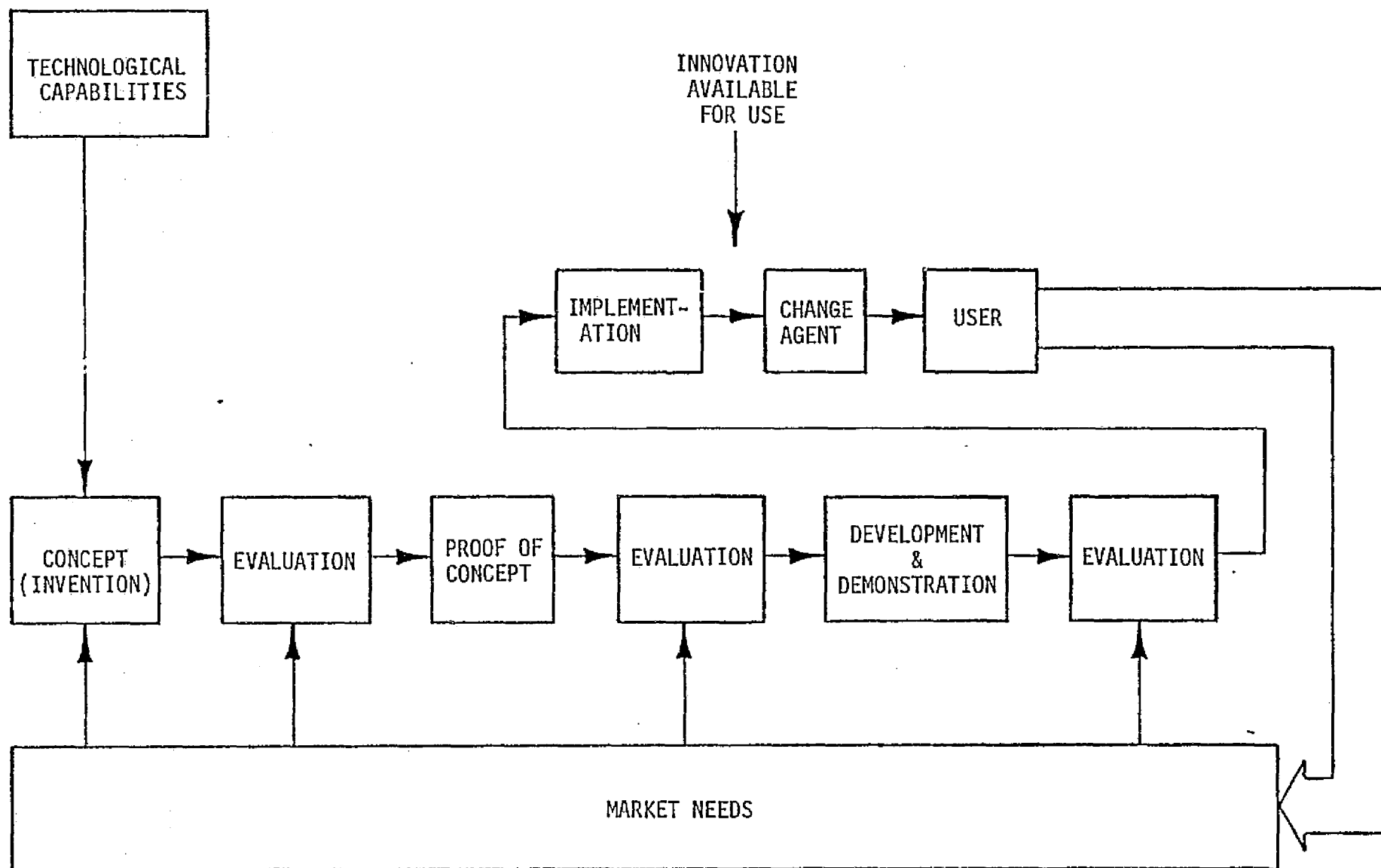


Figure 3.1 The Process of Technological Innovation

first is that the amount of time required for completion of this innovation process is quite long, on the order of several decades. In a recent study by Battelle of the development process, that is the portion starting with the concept and ending with implementation, ten specific innovation processes were studied. The time required for the development process in each of these innovations is given in Table 3.1. The average time span for these ten innovations is 10.2 years. The diffusion process, that is to say, the adoption of the innovation once it has become available, takes a period of about the same magnitude. Thus, a time span of 40 years from conception to wide-scale adoption is by no means unusual. Very seldom is it less than 10 to 15 years.

Time spans of this magnitude are larger than the planning horizons of most public or private organizations, and may cover several generations of decision makers. Many innovations fail simply because of a lack of continuity in the management structure.

The long time span is a major factor in the next general observation, which is that the failure rate in this process is extremely high, running from 98 to 99 percent depending on the definitions employed. The greatest number of failures occur in the earlier parts of the process, though failure in the marketplace, once an innovation has been implemented, is of the order of 50 percent. When the process is successful, the rewards both to the innovator and to society as a whole may be very large, but the possibility of failure is also quite high.

The next general observation is that most innovation processes show a merging of diverse streams of technology. That is to say, technologies which initially seem to be unrelated to the problem being

Table 3.1 Duration of the Innovative Process for Ten Innovations

INNOVATION	YEAR OF FIRST		DURATION YEARS
	CONCEPTION	REALIZATION	
HEART PACEMAKER	1928	1960	32
HYBRID CORN	1908	1933	25
HYBRID SMALL GRAINS	1937	1956	19
GREEN REVOLUTION WHEAT	1950	1966	16
ELECTROPHOTOGRAPHY	1937	1959	22
INPUT OUTPUT ECONOMIC ANALYSIS	1936	1964	28
ORGANOPHOSPHORUS INSECTICIDES	1934	1947	13
ORAL CONTRACEPTIVE	1951	1960	9
MAGNETIC FERRITES	1933	1955	22
VIDEO TAPE RECORDER	1950	1956	6
AVERAGE DURATION			19.2

considered are brought into the process. This happens throughout the process, and not only in the early phases. In most cases this merging appears to have been largely fortuitous. This has caused some investigators to wonder whether the process can really be managed at all. However, in some cases innovations have been developed by multidisciplinary teams convened specifically for the purpose of producing a desired innovation, and in these cases the merging of technologies appears to be planned.

Finally, it has been observed that in most successful innovations there is an advocate. This is an individual, sometimes the inventor, sometimes not, who devotes a substantial number of years to furthering the idea. In some of the literature this person is called a technological entrepreneur. Because of the time span involved in innovation the technological entrepreneur may well devote his entire career to furthering a single idea. The presence of such an individual was observed in all but one of the innovations studied.\*

It should perhaps be mentioned that there are certain terminology problems in the discussion of technological innovation. There is as yet no standard terminology in this field and the new Technology Transfer Society has taken this as an item for early action. The terminology used here may differ in some respects from that found in certain other books and papers.

In the following subsections some discussion is given of each of the steps in the process. The conclusions presented here are drawn

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\*Science, Technology and Innovation. Battelle Columbus Laboratories. February 1973. PB 22859.

from a wide variety of studies which have been made. Perhaps the best guide to the development process (from conception until the product reaches the market) is the above mentioned Battelle study. For the remainder of the process a good summary and guide to the literature is given by Rogers and Shoemaker.\*

### 3.1 The Concept or Invention

Available studies suggest that inventors or people who produce new conceptual solutions to problems are a rather special type of individual. Most inventors invent continuously. They enjoy invention more than other parts of the process and indeed they are typically not well suited for carrying out the remaining steps. Furthermore it appears that, in the case of patentable inventions, most are made by individuals associated with the application area. That is to say, railroad inventions are made by people associated with the railroads, etc.

It has, however, proved possible to produce inventions by various types of group interactions. Sometimes this involves groups of inventors, and other times, they are groups of individuals encompassing the technical areas that appear to be relevant.

It seems clear that most inventions do not reach the stage of application. The high failure rate in the innovation process has already been mentioned. Of patented inventions, about half are applied, at least to some extent. Of course, obtaining a patent is a moderately expensive activity and is usually not undertaken until some of the evaluation steps have been completed.

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\*Everett M. Rogers and F. Floyd Shoemaker, *Communication of Innovations, A Cross-Cultural Approach*, Second Edition, The Free Press, New York (1971).

### 3.2 Evaluation, Validation, and Implementation

During the remainder of the development process, the Battelle study identified a number of significant factors. Among the more significant were the following:

1. Internal R&D management
2. Availability of funding
3. Presence of a technical entrepreneur
4. Interaction with in-house colleagues
5. Technology confluence
6. Presence of a technological gatekeeper.

Funding and management are obviously of importance. However, even when funding is available it is rather remarkable how often erroneous decisions are made. Even when serious efforts are undertaken to collect relevant data and to weigh all significant factors, wrong decisions are more the rule than the exception. This area appears to offer considerable potential for improvement. It has also been found that frequently important contributions are made by employees of the developing organization who are not directly involved in the innovation in question. They assist in the technology confluence, which is a significant factor in most successful innovations. The technological gatekeeper is another contributor to this confluence. He is an individual who is widely acquainted with technological activities and technological capabilities and is able to assist in assuring that the relevant skills and data are assembled.

### 3.3 The Adoption Process

In some ways the most critical part of the innovation process is that of bringing about actual use of an innovation which has become available. This involves three interrelated components: the innovation itself, the potential user, and the change agent. The change agent can take a variety of forms, ranging from an informational pamphlet to a symposium to an actual sales representative.

There are mutual interactions among these three entities and in the following subsections brief descriptions are given of the characteristics which tend to promote or inhibit adoption of the innovation.

#### 3.3.1 Characteristics of the Innovation

A number of studies have shown that the following attributes of an innovation are significant in influencing its adoption:

- Relative Advantage. Perhaps most significant is the degree to which the innovation offers an advantage over other techniques or equipment. How much money is saved, how much time is saved, what is the relative convenience, etc.
- Compatibility. If an innovation can be integrated smoothly into an existing operation its adoption potential is enhanced. If, on the other hand, new equipment must be purchased or new personnel must be hired with different skills, the innovation is less likely to be adopted.
- Complexity. If the innovation appears to the user to be unusually complex or difficult to understand he will have less tendency to adopt. The perception of complexity, of course, may be quite different for different individuals in a user community.
- Trialability. If an innovation can be tested on a small scale without making a full initial commitment it is more likely to be adopted. Perhaps the most notable example of a system with poor trialability is a new mass transit system. A large investment must be made before any benefits are demonstrated, and this is one reason why this innovation is so rarely adopted.



- Observability. This is the degree to which the results of adopting an innovation can be seen by the user, by the user's customers, or by the user's competitors. In one case, a pesticide failed to be adopted because it killed rats in their holes. It was not possible to see the effects of the poison, and the pesticide was therefore deemed to be ineffective.

### 3.3.2 Characteristics of the Adopter

Perhaps one of the most interesting features of the adoption process is its time distribution. If the number adopting per unit time is plotted as a function of time the result is a bell-shaped curve, as shown in Figure 3.2. The first group to adopt is the group of innovators. These are individuals or organizations who enjoy innovation and are able to indulge their tastes. In terms of the overall process this is not a very significant group.

The next group, however, the early adopters, is quite different. These are people or organizations who are accustomed to innovation and are highly regarded by the user community. Others look to them for leadership. They are usually more open to communication of all types than are other members of the community. Studies indicate that once the early adopters have made a favorable decision the rest of the community will follow along without major activity on the part of the change agent. This suggests, then, that the early adopters should be the principal target for the change agent. It should perhaps be mentioned that a majority of the work that has been done on technology transfer has been in the agricultural field where the adopters are typically individual farmers. It may be that the characteristics identified for early adopters in the technology areas studied to date are only relevant in part to the more common situation for NASA technology in which the adopter is an industrial organization.

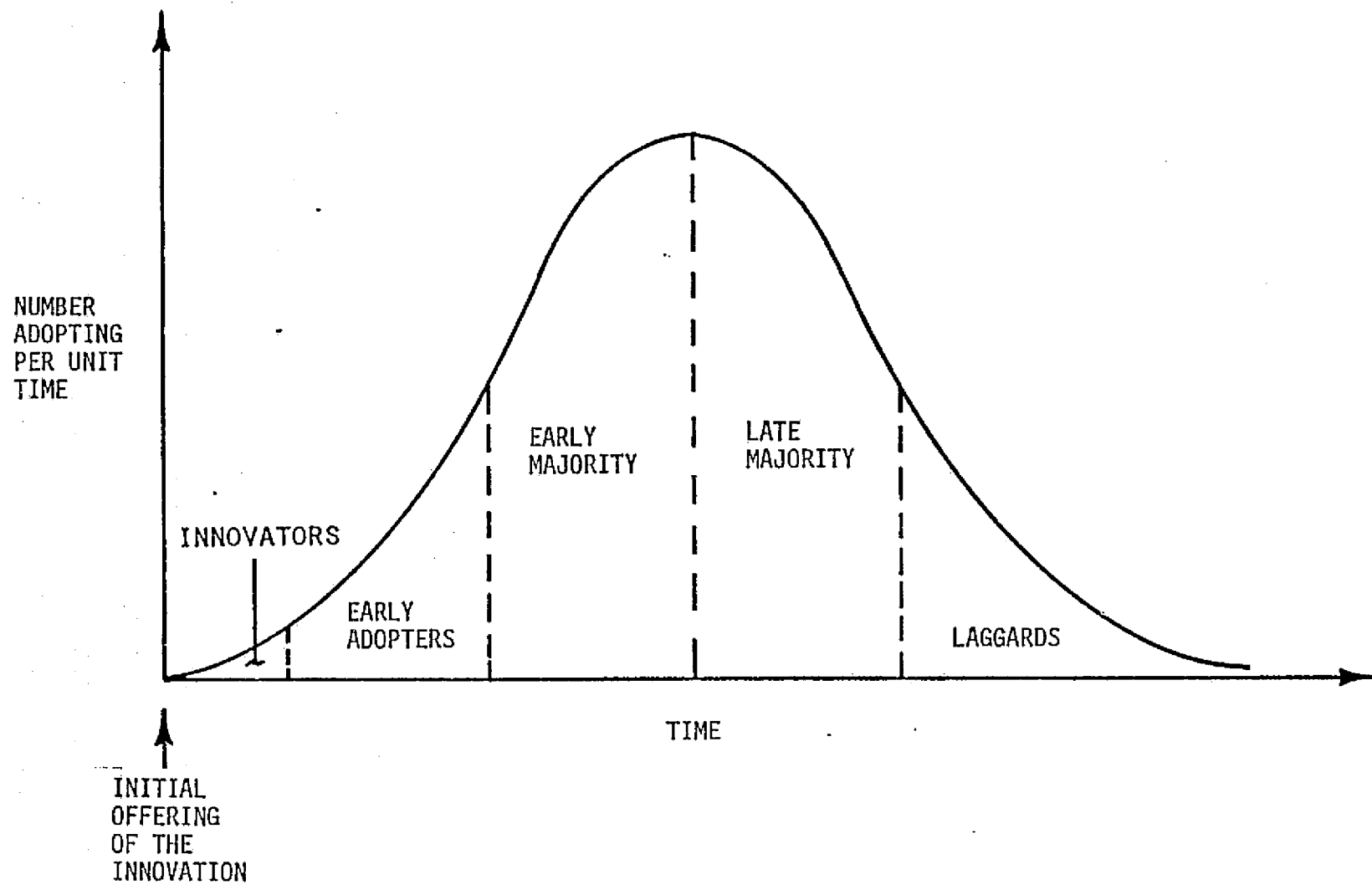


Figure 3.2 Adopter Categories

Turning now to the question of the adoption decision itself, there are some differences between individual adopters and collective adopters. If the innovation is to be adopted by single individuals, four stages have been identified. These are:

- Knowledge. In this period the user is generally aware of the existence of the innovation but knows little about it and has no particular opinion of its merits.
- Persuasion. In this phase the user becomes acquainted with the characteristics of the innovation and analyzes those characteristics in relation to his own needs. This is the phase in which the change agent is most effective.
- Decision. The user decides to adopt or to reject the innovation.
- Confirmation. Following his decision the user seeks additional information to determine whether or not he made the correct choice.

If the innovation is to be adopted by a group or organization then the process is somewhat different. The steps are the following:

- Stimulation. This is the phase in which the idea of the innovation is introduced to the organization, usually from outside.
- Initiation. During this phase the innovation is studied and its relevance to the organization assessed, usually at lower levels in the hierarchy.
- Legitimization. In this phase the more influential members of the organization become persuaded that the innovation should be adopted. This usually causes an affirmative opinion to diffuse throughout the organization.
- Decision. Once the various levels within the organization have become persuaded that the innovation should be adopted a decision can be rendered.
- Action. The plan of action associated with adopting the innovation is executed. In many cases this may be a rather complex group of activities.

### 3.3.3 Characteristics of the Change Agent

The change agent is the link between the innovation and the user, and can be defined as a process, an organization, or an individual who attempts to bring about use of the innovation. It has been determined that the following characteristics are positively related to a change agent's success:

- Effort. As might be expected, the more contacts made by the change agent the more likely that his efforts will be successful. As mentioned above, this effort is most useful during the early adopter phase.
- Client Orientation. A change agent will be more effective if he identifies with his clients rather than with the change agency.
- Social Status. The higher their social standing, the more effective change agents appear to be. There are limits, however. Too great a gap between the change agent and the client may be counterproductive.
- Working Through Opinion Leaders. Change agents who concentrate on the opinion leaders in the client community are demonstrably more successful than those who do not.
- Credibility. A change agent who has established credibility with clients will be more effective. It appears that NASA may have a particular problem in this area, at least when dealing with industrial clients.

There are many ways in which the change agent function can be implemented. Some of the more frequently employed functions are listed below. Many of these have been or are currently being used by NASA, other federal agencies, and by sales forces for high technology industries.

- Dissemination of Literature. Perhaps the simplest change agent device is that of sending out literature describing the innovation and outlining the reasons why it should be adopted. This technique is widely employed, possibly because it is relatively inexpensive; it is done by NASA Code K, by NTIS, and by most high technology industries.

- Reference and Literature Search Services. An organization which can respond to user inquiries by locating and transmitting reference material can also function as a change agent. This is done by NASA Code K, U.S. Department of Agriculture, NTIS, NIH, and others.
- Local Agents. The use of local agents to interface with users on a continuing basis can be a highly effective, though expensive, change agent mechanism. This is a feature of the world's most successful technology transfer operation, the system composed of the U.S. Department of Agriculture Extension Service, the state research organizations and the local county agents. This system, which is funded partly by the federal government and partly by the state and county governments, is widely viewed as the most successful technology transfer operation thus far achieved. It is given a major share of the credit in the outstanding productivity increase record of U.S. agriculture. It is true that the local agents are only one part of this system, but the success of their operation merits the close consideration of anyone involved in technology transfer. The NSF is currently conducting an experimental program in which technology agents are attached to city governments in a number of medium-sized U.S. cities. Their function is rather similar to that of the county agents and these technology representatives are supported by a backup system of research institutions.
- Regional Centers. Some organizations make use of a permanent facility to foster technology transfer in a region, perhaps one state or several states. While not maintaining the close tie with individual users that is possible with the local agent system, the regional centers can provide a wider spectrum of services and expertise. Such centers are operated by various high technology industries, by NASA Code K, by ERDA, and others.
- National Centers. Moving even further away from the close user interface, it is possible to operate technology transfer from a single center serving the entire nation. Industry seldom uses this approach, except when the number of potential customers is quite small. It is used by a number of federal agencies including NASA and NIH.

The selection among these various types of change agent configurations will be based on the nature of the innovation, the nature of the user community, and the importance which is attached to achieving a successful transfer. This last point can be translated into the question

of how much money is allotted. If the potential users are very numerous and widely dispersed and if transfer is sufficiently important, the local agent configuration might be the best. If the number of potential users is very small, then a national center would be indicated. If limited funds are available, perhaps literature dissemination and literature search services are indicated. Some recent experiments have shown that literature dissemination can be reasonably effective if the literature is prepared and distributed in the proper way. Careful targeting of literature and distribution mechanisms, however, increases the expense.

The choice, then, depends on a careful analysis of the marketing problem being addressed. Even for a single technological innovation such as SEASAT there are many different potential user communities. They vary from user communities with only a few members, such as a single federal agency, to user communities of millions of members, such as recreational boat operators.

4.1 Applications to the Offshore Oil and Gas Industries

By any standard, offshore oil and gas exploration and production constitutes the largest segment of economic activity in the world's oceans. It has been estimated\* that the economic value to the United States alone of offshore oil and gas was \$3.2 billion in 1973, and will grow to \$18.9 billion by the year 2000 (in 1973 dollars). The next largest segment is that of transportation, for which the comparable figures are \$2.5 billion and \$11.4 billion, respectively.

The size of this industry, together with the fact that there is a clear need for improved technology in offshore exploration and operation, suggests that this industry segment presents a major opportunity for application of the new and unique capabilities of SEASAT-A for generating data for all the world's ocean regions, with particular emphasis on the waters surrounding North America.

A number of initiatives are now being pursued with organizations involved in offshore oil and gas operations, with the objective of defining possible experiments which these organizations might undertake, utilizing SEASAT-A data, and investigating its practical benefits. For the most part, the organizations contacted have been highly receptive to the general idea of using SEASAT data, and to the development of suitable experimental programs. However, a number of details remain to be worked out. The purpose of this section is to

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\*"The Economic Value of Ocean Resources to the United States", prepared for the Committee on Commerce, U.S. Senate, pursuant to Senate Resolution 222, National Ocean Policy Study, 93rd Congress, 2nd Session, December 1974.

outline the general character of the potential experiments which are emerging from this negotiation process.

#### 4.1.1 General Nature of Offshore SEASAT Experiments

In contacts with the offshore industry, interest has been expressed in all the SEASAT sensors and in several geographical regions. There is interest in both real time and historical data. In some cases, potential experiments have predictive models to which SEASAT data could make a contribution. In all geographical regions the interests of the users are roughly similar. They are interested in:

1. Verifying SEASAT data against in situ measurements in the region of interest
2. Use of SEASAT data in "nowcast" and predictive models and verification of the model outputs
3. Use of the data obtained to guide field operations.

There will be a requirement for the most recent possible data for "nowcast" and forecasting purposes, very likely on the order of 12 hours or less. Collection of historical data in certain regions has been indicated to be quite useful for generating exceedance statistics.

Interest has also been expressed in using the sensors over certain land areas to determine surface topography.

#### 4.1.2 Methods of Data Application

##### 4.1.2.1 Comparison with Ground Truth

As an initial step in any experiment, users will want to verify SEASAT-A data against other measurements, especially those being made at existing facilities in the areas of operational interest. For this purpose real time data are not necessary. If agreement



with ground truth data is not obtained it will be necessary to investigate the causes for this disagreement before proceeding.

#### 4.1.2.2 Use of SEASAT Data in Models

Several prospective users have predictive models for ice movement, wave height, or weather. Once SEASAT data are verified they can be put into these models along with data from other sources. It may be possible to arrange to run predictions with and without the SEASAT data but user motivation to do this may not be high. Also, for the most part, these models are proprietary. In any case, model prediction will be compared with operating experience.

Again, if verification is not obtained, it will be necessary to investigate the discrepancy before proceeding.

#### 4.1.2.3 Operational Use of Data

If the preceding step is successful, the final portion of the experiment would be to make use of the data and predictive models to guide operational decisions. A number of months would be required to carry this out. It will probably not be possible to compare the results with SEASAT against those without, but it will be possible to keep track of key operational decisions in which the data played the major role.

#### 4.1.2.4 Use of Historical Data

As a possible adjunct to SEASAT data it may be of interest to make use of other available satellite measurements. For example, GEOS-3 data could be used to estimate wave height in regions of interest for the years in which these data are available.

### 4.1.3 Areas for Possible Experiments

The data requirements are generally similar for all geographic regions but there are some differences in emphasis. The regions discussed below are the ones in which the greatest interest has been expressed by Canadian and U.S. offshore oil and gas operators.

#### 4.1.3.1 Beaufort Sea

The major requirements are for monitoring fog, wave height, temperature, and ice dynamics as related to meteorological data during the summer. In winter the primary interest is in ice movement, ice classifications, and effects on the environment.

#### 4.1.3.2 Labrador Shelf

Here the interest is in waves, winds, currents, prediction of internal waves, and iceberg drift. Also, historical data on icebergs and waves are needed for design purposes.

#### 4.1.3.3 Gulf of Mexico

Interest here will probably be in monitoring and prediction of winds, waves, and temperatures, especially in relation to major storms.

### 4.1.4 Experiment Duration

It seems probable that the time span of one and one-half to two years will be required to reach the point in which operational use could begin. Once SEASAT-A data become available, perhaps three months would be required to get the data channels working, assuming good advance planning. In the Arctic locations, probably a full operating

season would be required for each of the two validation steps, assuming all goes well. If discrepancies are found, additional time will be required to find the causes.

At least another year would be required before a reasonable opinion could be developed as to the operational usefulness. Thus, a total program of the order of three years could be involved, possibly longer if problems are encountered.

#### 4.1.5 Experiment Organization

The organizational structure to be employed in the experiment will be strongly dependent on the offshore operating organization selected. In the case of large companies or consortia, there would be very little involvement of NASA. They would probably make use of specialized contractors to carry out parts of the activity.

In the case of smaller companies, considerable NASA assistance might be required in data handling and/or interpretation.

The data requirements seem rather similar for all the various possible experiments, so most offshore operator requirements could probably be met by a single SEASAT data system. This suggests that, once this system is designed, it could be made available to the entire industry and that a considerable number of users might benefit, at minimal cost to NASA.

This further suggests the possibility of an experiment covering the entire offshore oil and gas industry, under a single management organization. With this structure, several separate experiments could be operated in different geographical areas, and with different industry organizations, both small and large.

## 4.2 Applications to the Marine Transportation Industry

### 4.2.1 An Ocean Routing Experiment

The purpose of the SEASAT-A Ocean Routing Economic Verification Experiment is to obtain experimental data in support of previous empirical estimates of the economic benefits of a SEASAT system which generates ocean condition information and which, along with conventional ocean condition information, is useful in routing vessels on ocean crossings. The aim of the ocean routing process is to assist vessels in their efforts to avoid adverse weather and the resulting problems:

- Loss of time
- Greater fuel consumption
- Casualties with loss of life and/or vessel damage.

The experiment will attempt to quantify the incremental reduction in time loss, fuel consumption and casualties when SEASAT information is added to the conventional information available. For a preliminary assessment of the usefulness of SEASAT-A for ocean routing see: Marine Transportation Cost Study.<sup>\*</sup> The results of this study are presented in Figure 4.1. Undiscounted benefits on U.S. trade routes alone might be \$27 million in the first full operating year, 1985. U.S. flag ships carry about 7 percent of the cargo on U.S. trade routes.

The experiment will be conducted through an actual monitoring of selected ocean crossings in a case study framework. The dollar value of the incremental gains will be estimated for the case study experiment, and the results will be generalized to all vessel ocean crossings on the U.S. trade routes for the time period 1980-2000.

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<sup>\*</sup> Marine Transportation Case Study, Volume VII of the SEASAT Economic Assessment, prepared by ECON, Inc., for the National Aeronautics and Space Administration under Contract No. NASW-2558, October 1975.

		Dry Cargo				Tankers		Totals Estimated		
		All U.S. Trade Routes		Canadian Trade Routes		World Fleet All Major Routes				
Source of Benefits		1985 Undiscounted Benefits	1985-2000 Cumulative Discounted Benefits*	1985 Undiscounted Benefits	1985-2000 Cumulative Discounted Benefits*	1985 Undiscounted Benefits	1985-2000 Cumulative Discounted Benefits	1985 Undiscounted Benefits	1985-2000 Cumulative Discounted Benefits*	
Direct Operating Costs	{	Delay Time Cost Savings	20,660,000	86,620,000	6,440.00 to 7,220,000	25,200.00 to 43,800,000	3,430,000 to 16,680,000	19,400,000 to 94,250,000	30,530,000 to 46,560,000	131,220,000 to 224,670,000
		Prevention of Cata- strophic Losses	(not estimated)		5,000,000	24,500,000	5,830,000 to 19,420,000	32,930,000 to 109,800,000	17,230,000  to  60,720,000	84,270,000  to  300,240,000
		Reduction in Casual- ty Costs (Hulls)	6,400,000	26,840,000	to	to	(not estimated)			
		Reduction in Casualty Costs (P&I cargo)	(not estimated)		39,900,000	163,600,000	(not estimated)			
Totals Estimated		27,060,000	113,460,000	11,440,000 to 44,120,000	49,900,000 to	9,260,000 to	52,330,000 to	47,760,000 to	215,490,000 to	

\* Discount Rate - 10%

Source: VII - SEASAT

Figure 4.1 Overall Results, Benefits Due to SEASAT in Marine Transport, in 1975 Dollars

#### 4.2.1.1 Background--The Present Weather Routing System

There is no single weather routing system today. Rather, there are the Navy's Fleet Numerical Weather Center (FNWC), Norfolk, Virginia and Monterey, California; and a number of commercial services such as Louis Allen, Washington, D.C.; Bendix Commercial Service Corporation, South Hackensack, New Jersey; Ocean Routes, Inc., Palo Alto, California. In addition, there are weather routing services operated by foreign individuals and governments. Bracknell, a government owned-routing service in England, is an example of the latter.

The charge per ocean crossing for these routing services may run from \$95 to \$300, but is generally in the \$200 to \$250 range. The charge may be for simply recommending the entire route in one analysis before the crossing begins or it may involve a more complete service. In its most thorough form the weather routing might involve a discussion with the captain before departure to gather such information as: what is the cargo to be carried; will any of it be stored on deck; is there any special reason that a speedy crossing is necessary. A recommended route will then be selected based on the information gathered from the captain, from weather forecasts, from information about the ship's rated speed and ability to handle heavy seas, etc.

Once the voyage is begun the weather router may contact the ship with revised information or suggestions as to the route as often as twice a day. FNWC runs its forecasting program and ship routing program twice a day. Navy ships often have a radio operator on duty continuously. However, for commercial vessels route recommendations are restricted to usually one contact per day since most commercial vessels have one radio

operator who will be on duty nine hours per day (usually in three-hour daylight shifts with one hour between shifts). When the voyage is completed, the routing service may also involve a post-voyage consultation and analysis. The ship's log book may be examined in conjunction with a record of the router's recommendation, to ascertain the cause of a slow crossing time or failure to avoid a heavy storm, or the reason for the departure from the recommended route.

The above description pertains to a complete weather routing service. Often contact is made only every few days, whenever a major change in weather conditions on the route takes place, and there may not be a post-voyage analysis.

Weather routing became available in the early 1950s, but the expansion of the weather routing services did not occur until the mid-1960s. Presently, on a given day, Ocean Routes, Bendix, Louis Allen, Inc., FNWC Monterey, and FNWC Norfolk may handle 850 ships. These numbers may vary considerably day to day. For example, Ocean Routes may handle 1000 ships on a given day and FNWC Monterey may handle 200 plus ships during a major military supply effort. Since 11,000 to 12,000 of the world fleet of approximately 21,000 ships may be on the ocean on a given day, the U.S. commercial and government weather routing services could be guiding approximately 7 percent of all ships on the oceans.

#### 4.2.1.2 Overview of Approach to Experiment

The experiment will seek three representative sample groups of ocean crossings from the vessel types and routes of interest. These three sample groups will be unrouted vessels, vessels routed without SEASAT, and vessels routed with SEASAT. The sample vessels will be provided ocean

routing information (if required) and monitored with respect to crossing time, fuel consumption and adverse weather related damage.

An extensive ocean routing industry exists today, and the SEASAT information will be an additional input to the procedures used by the industry. The ocean routing industry will provide the routing service where required. The ship owners will be approached to seek their cooperation in the monitoring effort. Ship owners will be asked to provide enough pre-voyage information to identify potential sample crossings and to provide desired post-voyage information.

ECON will collect the post-voyage information and subject it to a screening process to determine if it is a representative sample. Those ocean crossings which pass the screening process will be entered in the sample data base. The differences in the performances of unrouted vessels, vessels routed without SEASAT, and vessels routed with SEASAT will be computed and analyzed. Dollar benefits for the use of SEASAT information in the ocean routing procedure will be derived from the analysis of the experiment results.

#### 4.2.1.3 Methodology Proposed

In order to provide an accurate assessment of the impact of a SEASAT system on ocean routing a sound methodology must be developed and implemented. In this section a methodology is presented which is intended to measure the incremental dollar benefits derivable from reduced ocean crossing time, fuel consumption, and adverse-weather related casualty damage.

The elementary unit in the experiment will be a single one-direction ocean crossing by a vessel of a given type or subtype. The



variables to be measured include: the crossing time, distance traveled, fuel consumed, and any casualty causes and costs. The physical field within which the experiment is to be conducted will be identified by: port of origin, port of destination, minimum distance possible (Great Circle route distance), ocean to be traversed, and time of year. The population of elementary units for this experiment will be all ocean crossings on the U.S. trade routes for the years 1977 to 1980 inclusive.

This population will be divided into three groups:

1. Unrouted vessels
2. Vessels routed without the use of SEASAT data
3. Vessels routed with the use of SEASAT data.

Representative samples will be drawn from each of these three population groups. The first sample group, the unrouted vessels, will be the Control Group, the second and third sample groups will be the Experimental Groups I and II respectively. The goal of the experiment is to quantify the difference in the measurement variables (crossing time, distance traveled, fuel consumed, and any casualty causes and costs) between:

- Control Group (unrouted vessels) and Experimental Group I (vessels routed without SEASAT data)
- Control Group and Experimental Group II (vessels routed with SEASAT data)
- Experimental Group I and Experimental Group II.

The success of the experiment will depend on the ability of the sample selection procedure to yield representative samples. This is especially difficult in this case because many factors affect ocean crossing time. Section 4.2.1.4 identifies these factors, and Section 4.2.1.5 suggests a method for obtaining representative samples given many such variable factors.

#### 4.2.1.4 Factors Affecting Vessel Performance

The factors which affect a vessel's ocean crossing performance may be grouped into three categories:

- Vessel specifications
- Geographic specifications
- Trip specifications.

Vessel specifications include all the physical characteristics of the ship which affect its performance. Among these are: when it was built, where it was built, gross tonnage, deadweight tonnage, speed, draft, engine type, beam length, etc. It is imperative that representative sample groups include vessels which are similar or nearly similar with regard to the variables which impact on the ocean crossing performance.

Geographic specifications include: the ocean of operation (and the specific path across that ocean), the port of destination, intermediate stops if any, direction of sailing, time of the year and direction of currents at that time of the year.

Trip specifications encompass the myriad of variables which change in the environment surrounding a given physical vessel in a given geographic setting. A sampling of these are: weather conditions, wave height, changes in crew, machinery failure, cargo type carried, load factors, on-deck cargo, etc. It is, of course, trip specifications which present the greatest control problem for this experiment.

#### 4.2.1.5 Selecting a Representative Sample

Selecting representative sample groups involves selecting elementary units (ocean crossings) which are similar or nearly similar with respect to vessel specifications, geographic specifications and trip specifications. In an ideally controlled case the only difference among the

control and experimental groups would be the availability or lack of routing information. The sample design should approximate this ideal as closely as possible.

The first step will be to stratify vessels by type and physical characteristics. This involves some subjective judgment. For example, a generally used broad classification by vessel type is:

- Liquid bulk (e.g. tankers)
- Dry bulk (e.g. ore carriers)
- Break bulk (e.g. freighters)
- Containers.

The Maritime Administration has adopted a slightly more defined broad classification for most of its analysis which includes nine vessel types:\*

- General cargo
- Partial container
- Full container
- Barge carrier
- Neo bulk
- Dry bulk
- Liquified gas carrier
- Liquid bulk
- Combination carrier.

An example of a very detailed classification can be found in the 99 vessel type classifications employed by the U.S. Salvage Association in

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\* A Study of the Future Requirements for Ships That Will Be Engaged in the U.S. World Trade for Both the Short and Long Term, prepared by Temple, Barker & Sloane, Inc., for the Office of Maritime Technology, Maritime Administration, March 1976.

its casualty survey procedure.\* A level of detail of vessel type will be selected so that, together with the physical characteristics selected, the vessels within each vessel type can be expected to perform similarly with respect to the measurement variables (ocean crossing time, fuel consumption, and cost of repair for weather related casualty damage).

Physical characteristics of vessels can be looked at in greater or lesser detail also. The characteristics used to physically describe a vessel will first be listed, then ranked according to their impact on the measurement variables. Ranges of value for each physical characteristic will be defined so that ships within a range can be said to be similar with respect to that characteristic alone. Ranges will be defined most narrowly for those characteristics ranked highest.

The aim of this effort will be to select strata of vessels, with each strata distinguished by type and physical characteristics, such that the vessels within each strata can all be expected to perform similarly with respect to the measurement parameters if they are placed in the same geographic situation and trip specific situation. These vessels within each strata will be called vessel subtypes.

Since it will be possible to perform a thorough analysis on only a few of the vessel subtypes, two criteria will be used to select the vessel subtypes to be analyzed:

- Vessel subtypes selected for analysis should be fairly representative of the broader vessel type within which they are found.
- The population of vessels for the chosen subtype should be sufficiently large that adequate samples can be drawn.

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\*U.S. Salvage Association, Inc., Damage Survey Analysis Coding Manual, January 1968, revised, April 1971.

The second step in selecting representative samples will be proper definition of geographic specifications. This is the simplest and most direct task and involves defining the ocean crossing of interest by:

- Port of origin
- Ocean to be crossed and general path to be followed
- Port of destination
- Time of year.

The first three define what will be called a route. The criteria for selecting the geographic area for the sample will be that a chosen route must be heavily traveled by the vessel subtype of interest, and the time of year must be such that adverse weather is an important consideration for the crossing. There are several published sources which can serve as a guide to vessel traffic by route.

Once the vessel specifications of the subtypes are selected and the geographic specifications defined, all elementary units falling within these specifications will be considered potential sample units. Data will be sought from as many of these units as possible. Scheduled ocean crossings by as many such vessels as possible will be considered for monitoring. The crossing will be identified as a potential sample element before the sailing, cooperation of the vessel owner will be sought, and a post voyage analysis will be performed by the shipping company which is expected to yield all the relevant trip specifications (i.e., load factor, type cargo, etc.). This implies it would be best to obtain the cooperation of a set of companies operating on the routes of interest.

Thus, the third step in selecting a representative sample involves defining as many quantifiable trip specifications as are relevant to the measurement variables and preparing a form which enables consistent information to be gathered. Space must be provided for entering qualitative information which impacts on the measurement variables. Ships' owners will be briefed before sailings on the quantitative and qualitative information sought and its ultimate use.

Post voyage trip specifications will be screened in order to eliminate those crossings which cannot be included in the sample (e.g., vessel left route for reasons unrelated to adverse weather) or to further stratify the sample (e.g., into vessels with high, medium, low load factors).

#### 4.2.1.6 Experiment Operational Considerations

Implementation of the proposed methodology involves identifying the appropriate source of data, designing an operational procedure for gathering the data and analyzing it, and developing the necessary computer processing software through which the data must flow. These considerations are discussed in this section.

#### Sources of Data

Vessel specifications can be found in the Maritime Administration's Ship Description System (SDS) file.\* This magnetic tape file contains specifications for 22,400 vessels or the bulk of the world fleet. The information on each vessel includes:

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\* Ship Description System, magnetic tape file maintained by the Office of Management Information Systems, Maritime Administration, U.S. Department of Commerce, Washington, D.C.

- Vessel name and flag
- Vessel number (Marad identification number)
- Vessel type
- When and where built
- Gross tons, deadweight tons, bale cubic
- Speed
- Draft
- Engine type
- Length beam
- Refrigerated capacity.

This information has been compiled by the Maritime Administration from the ship registries such as Lloyd's Register of Shipping and the American Bureau of Shipping. A computer program will be created to cluster the vessels into the appropriate groups according to the vessel specification ranges provided. The program can be rerun with various vessel specifications until a satisfactory stratification is achieved.

Geographic specifications such as general weather conditions by time of year, ocean conditions and currents can be obtained from ocean routers such as Fleet Numerical Weather Center, Ocean Routes, and Bendix Commercial Services Corporation. Traffic on routes by vessel type can be obtained from:

ECON, Inc., Marine Transportation - Case Study and Generalization, Volume VII of SEASAT Economic Assessment, prepared for the U.S. National Aeronautics and Space Administration, May 1976. (Includes forecasts.)

Temple, Barker & Sloane, Inc., A Study of the Future Requirements for Ships That Will Be Engaged in the U.S. World Trade for Both the Short and Long Term, prepared for the Office of Maritime Technology, Maritime Administration, March 1976. (Includes forecasts.)

Maritime Administration, Essential U.S. Foreign Trade Routes, annual.

Trip specifications can be obtained from the ship owners.

Weather routing without and with SEASAT will be provided by the ocean routing services in the normal course of their operations in the period 1977 to 1980 (1977 and part of 1978 without SEASAT, part of 1978 through 1980 with SEASAT). Routed vessels will necessarily be restricted to the customers of the routing service. Sample crossings of vessels routed without a SEASAT system will be drawn from the 1977 to mid-1978 population. Sample crossings of vessels routed with a SEASAT system will be drawn from the world 1978 through 1980 population. Since it will be necessary to gather the data for the two experimental groups in sequence rather than in parallel (once SEASAT derived information becomes available it would not be ethically acceptable to withhold that information from some vessels since the safety of lives and property are at stake) extra care must be taken that all other specifications are as similar as possible. SEASAT information will be provided directly to the Fleet Numerical Weather Center and distributed by them to ship routers who will use this information in their routing recommendations.

The trip specification data will be keypunched (if it passes the final screening) and entered into a main data base. A computer program will be created to process and analyze this data and calculate the benefits of the SEASAT information.

#### Operational Procedures

The operational procedures described in the methodological discussion and data sources description are summarized here.



1. Select vessel type and physical characteristics for experiment.
2. Select route and time of year in which to conduct the experiment.
3. If the vessel is routed the ocean router takes ocean condition forecast (using SEASAT information if available) and vessel data, prepares routing instructions, and provides the routing instructions to the ship before departure.
4. After departure ship reports are received along with updated ocean condition forecasts, and the route selection is updated; this process is repeated as often as necessary until the vessel arrives at its destination.
5. After the voyage is completed the trip specifications are entered on a form provided to the ship owners by ECON and the completed form is sent to ECON.
6. The forms are analyzed by ECON and the ocean routers, and if the ocean crossing is deemed representative the crossing is included in the sample data base; and the general results are calculated when the sample sizes permit significant results to be derived.

These operational procedures are illustrated in Figure 4.2, Flowchart of Operational Procedures. The roles of the experiment participants in each of the operational steps is given in Table 4.1, General Operational Roles of Experiment Participants.

#### Data Flow and Experiment Results

The data flow and processing described throughout the methodological discussion and data sources description are summarized here.

1. Identify general vessel types (4 to 9 types).
2. Identify a representative or significant (in terms of volume of cargo) vessel subtype.
3. Select identifying vessel specifications ranges for the empirical subtype.

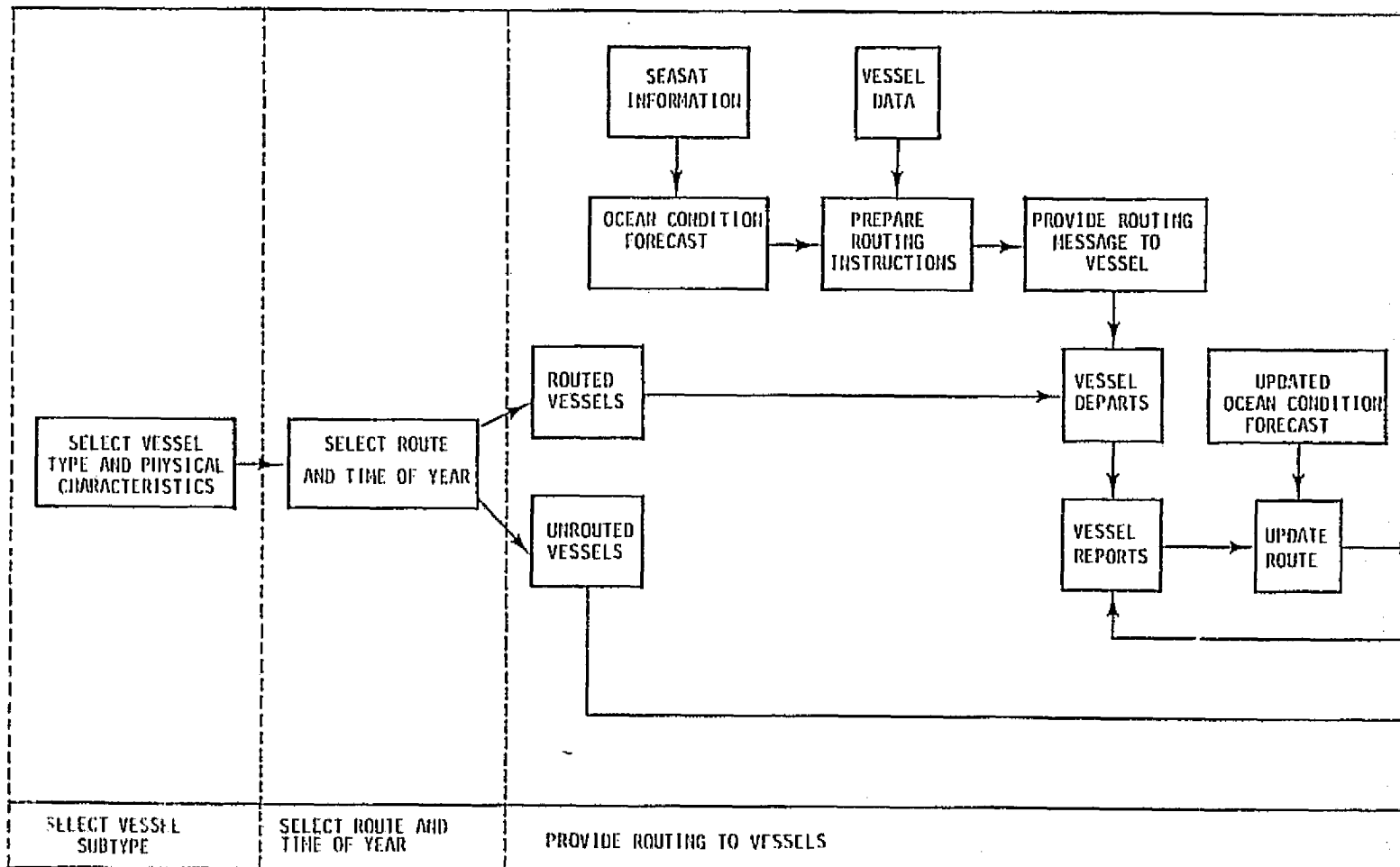
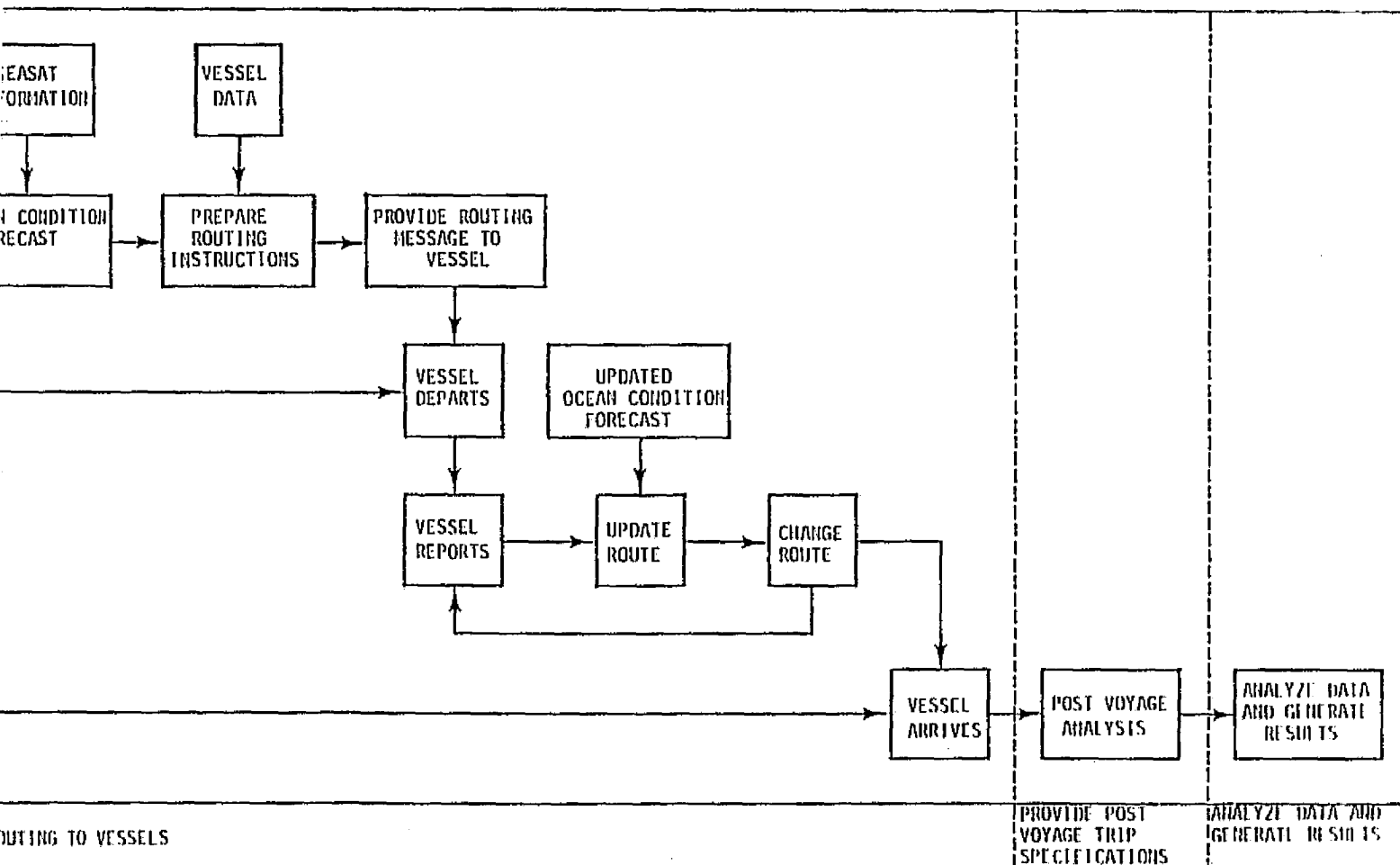


Figure 4.2 Flowchart of Operational Procedures, Ocean Routing



Flowchart of Operational Procedures, Ocean Routing Case Study

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Table 4.1 General Operational Roles and  
Experiment Participants

Operational Steps	ECON	Ship Routers	Ship Owners
Select Vessel Subtype (vessel specifications)	✓ (with SDS file provided by Maritime Admin.)	✓ (technical assistance to ECON)	
Select Route & Time of Year (Geographic Specifications)		✓	
Routing Provided to Vessels		✓	
Provide Post Voyage Trip Specifications			(to ECON on ✓ form devised by Ship Router and ECON)
Analyze Data & Generate Results	✓		

4. Write computer program to cluster vessel names from Maritime Administration's SDS file into subtypes identified by ranges of vessel specifications.
5. Run cluster program with Maritime Administration's SDS file as input and list of vessel names grouped by subtype as output.
6. Identify oceans, routes, and time of year of interest.
7. Ship routers select tentative sample from the cluster list where it overlaps their customer list and solicit cooperation of the shipping companies.
8. ECON contacts and solicits the cooperation of shipping companies whose ships are on the cluster list and who do not receive ship routing.
9. Check sample ships for any major modifications (eliminate if yes).
10. Select potential sample crossings (elementary units) in advance of sailings.
11. If a routed ship, provide ship routing for the crossing (some without SEASAT data, some with SEASAT data).
12. After voyage collect all trip specifications for all sample ocean crossings.
13. Eliminate unrepresentative elementary units (e.g., vessel departs from test route for reasons unrelated to weather).
14. Further group elementary units according to trip specifications.
15. Enter representative elementary units into data base.
16. Run program to perform quantitative and economic benefit analysis.
17. Perform generalization of sample results to population.

This procedure is illustrated in Figure 4.3, Data Flow and Computer Processing.

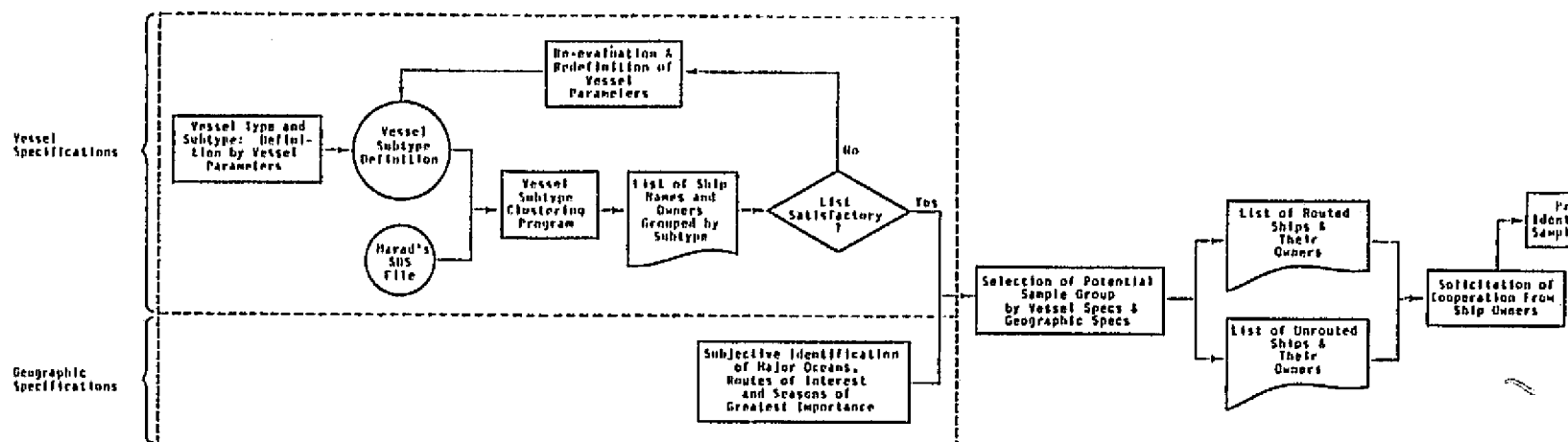


Figure 4.3 Data Flow and Computer Processing SEASAT Economic Verification Ocean Routing Case Study

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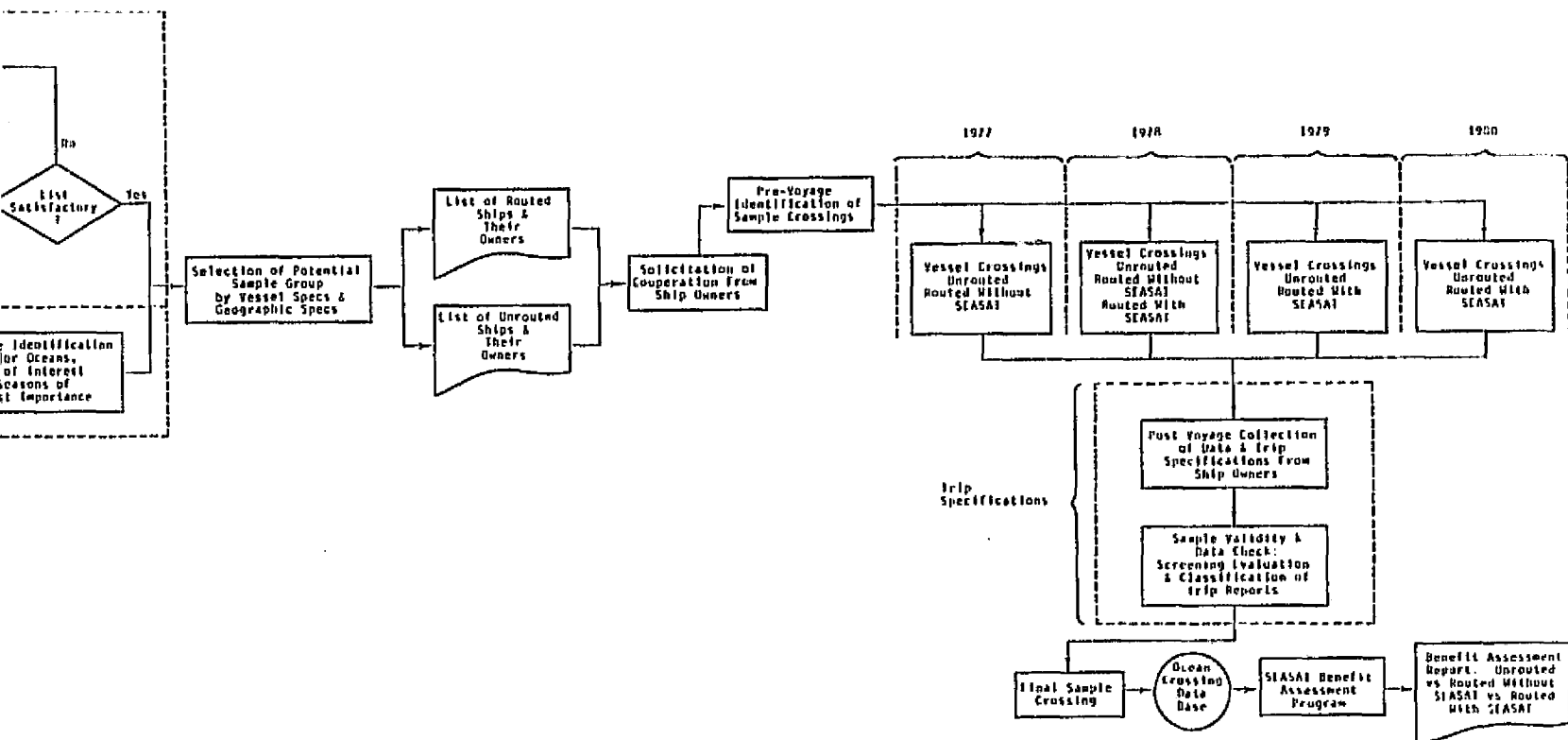


Figure 4.3 Data Flow and Computer Processing SEASAT Economic Verification Ocean Routing Case Study

## 4.2.2 A Ship Routing Experiment in the Belle Isle Straits

### 4.2.2.1 Introduction

Shipping traffic entering or departing the St. Lawrence can choose to pass through either the Belle Isle Strait or Cabot Strait. For European traffic, choice of the Belle Isle Strait results in transit time savings of up to 24 hours as shown in Figure 4.4 . Unfortunately, the ice-free season at Belle Isle Strait is a very brief one, usually lasting from August 1st through mid to late November. In addition, fog and other adverse weather conditions make ice and iceberg reconnaissance difficult. Routing decisions are made with incomplete information, and are often made conservatively.

A "Belle Isle Strait" experiment is proposed to estimate some of the economic benefits of the sea ice and iceberg information provided by SEASAT's microwave radiometer and synthetic aperture radar. The benefits to be examined would manifest themselves through changes in routing patterns of European shipping through the two straits. These benefits would be measured in saved shipping days, improved safety and reduced fuel consumption. The experiment may also provide an indication of further increases in shipping efficiency to be expected from the fully operational SEASAT system.

### 4.2.2.2 The Problem

Vessel traffic on the trade routes between the Gulf of St. Lawrence and Northern Europe is subject to marked deviations from the shortest navigable distance tracks due to the ice fields. Most steamship operators offer their vessel masters standing orders to circumnavigate all known ice by at least 60 to 100 miles. To and from the Gulf



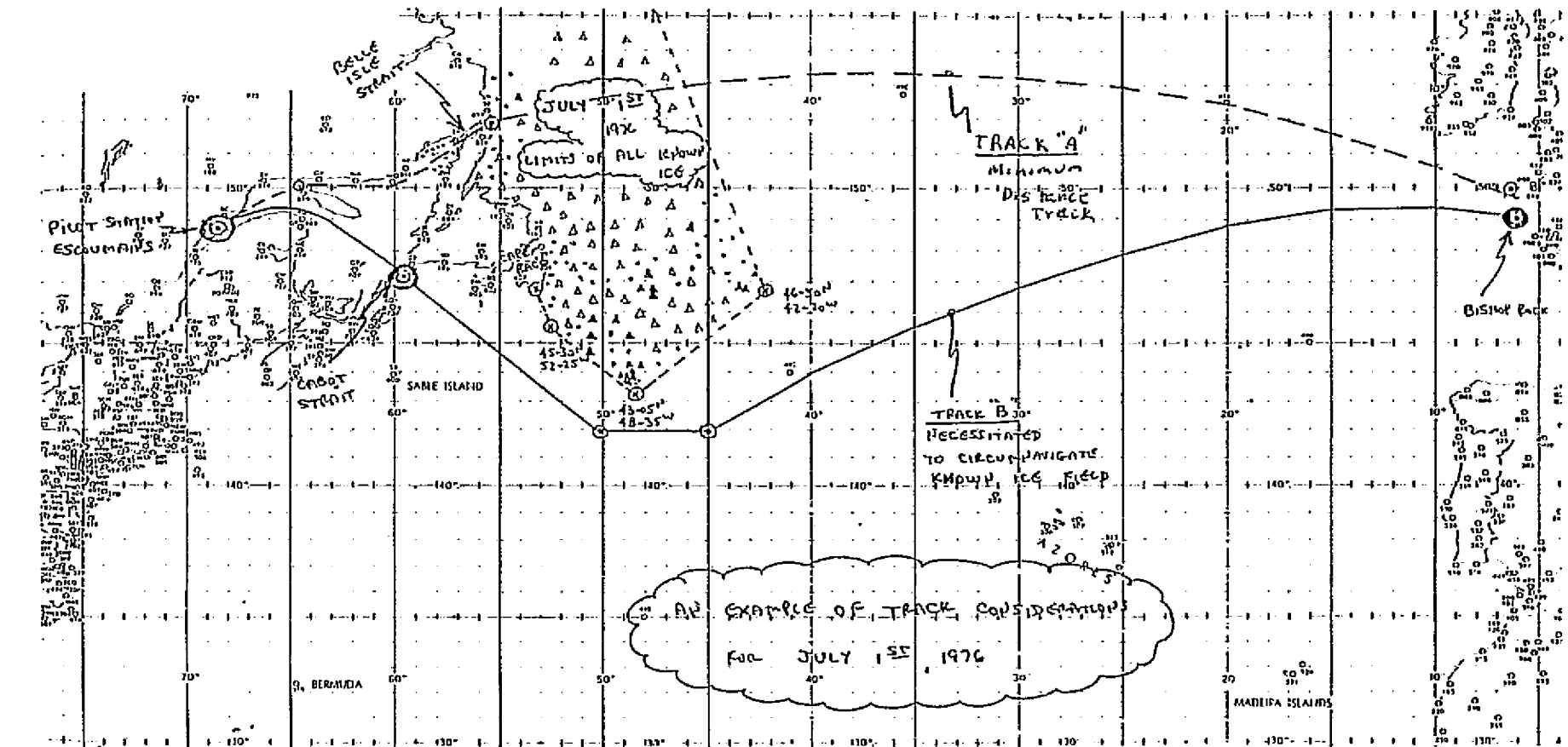


Figure 4.4 Alternate Routes for St. Lawrence - European Traffic

\*Bendix Field Corporation.

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of St. Lawrence, the minimum distance track would normally involve the use of the Belle Isle Strait, north of Newfoundland. However, the ice-free season at Belle Isle Strait is a very brief one, usually stretching from August 1st through mid or late November.

The alternative for this trade route traffic is to utilize the Cabot Strait, west of Newfoundland, and add significant distance to the voyage. This means additional costs and could mean further delays due to encountering additional weather en route.

A typical example of the distance difference involved between the utilization of Belle Isle Strait and Cabot Strait follows:

Track A (Via Belle Isle Strait)  
2459 Miles Escoumains to English Channel

Track B (Via Cabot Strait)  
2859 Miles Escoumains to English Channel

These routes are illustrated in Figure 4.4. Note that Track B is 400 miles longer than Track A. A 15-knot vessel could therefore lose 26.7 hours of transit time if committed to transit Track B when the Belle Isle Strait and its approaches were "ICE-FREE". Based on operating costs of \$3,000 per day,\* this amounts to \$3,340 per diverted ship.

#### 4.2.2.3 Background

Belle Isle Strait is closed by sea ice from January through June, with slight variations in these times from year to year. Very little traffic uses the strait during this time. The shipping traffic through Belle Isle increases after June, though there are many icebergs in the area until August. A few icebergs may still be present in

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\*Bendix Field Corporation.

September. Sea ice begins to return to the Strait area in late November, and the sea traffic correspondingly decreases.

European shipping traffic through the St. Lawrence consists largely of exports of grains and scrap metals, and imports of fuels, finished metals and metal products. Approximately 1,300 ships travel through the Cabot and Belle Isle Straits during the months of May, June and July. During this transition period, the Belle Isle Strait becomes navigable. Approximately 30 percent (400) of this number represents European traffic, and at most 130 of these voyages passed through the Strait of Belle Isle. We can assume that the bulk of the 270 European voyages not using the Belle Isle Strait were deterred by perceived ice conditions in the Strait, resulting in operating losses on the order of \$900,000.\*,\*\*

The efficiency of European shipping traffic routing during this transition period is particularly sensitive to the quality of ice information that is available to the shippers.

Ice information for the mouth of the St. Lawrence is collected and distributed in a variety of ways. The area of interest is roughly split into two jurisdictions: the Cabot Strait--Grand Banks area is monitored by the U.S. Coast Guard's International Ice Patrol, while the Gulf of St. Lawrence, Belle Isle Strait and the northern areas of Newfoundland are monitored by the Canadian Atmospheric Environmental Service's Ice Forecasting Central. The above jurisdiction division, illustrated in Figure 4.5, is an informal one. In fact, the regions

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\* Communication with Robert Raguso, Bendix Field Corporation, August 1976.

\*\* Communication with Lucien Misson, Canadian Department of Transport, August 1976.

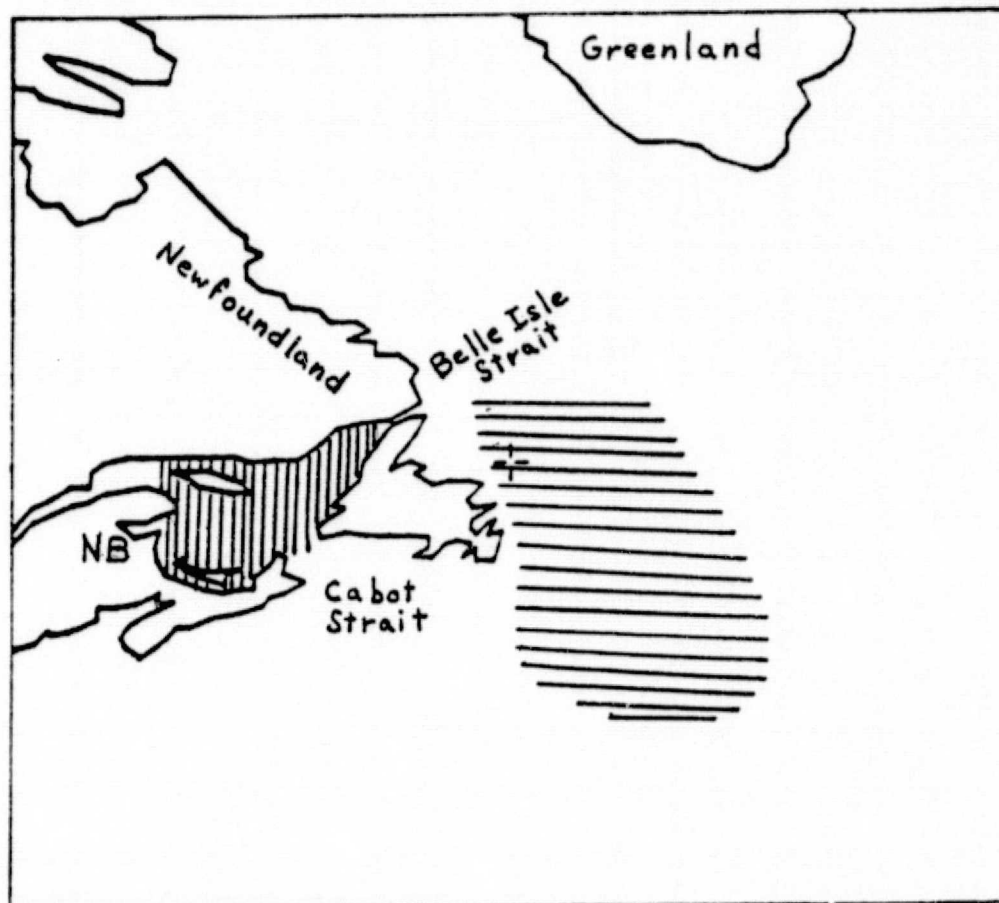


Figure 4.5 Principal Ice Surveillance Areas

KEY



Canadian Ice Central

USCG International Ice Patrol

of interest for each group overlap. The two groups cooperate in ice information collection for the area.

The International Ice Patrol (IIP) is active during the months of January through July. Its primary task is the location of sea ice and icebergs in the Grand Banks region southeast of Newfoundland. The IIP surveys ice conditions during this period through ship reports and aerial (visual and radar) ice reconnaissance. During the 1973 season, there were 77 flights, 11 of which were in June and 9 of which were in July. Figure 4.6 illustrates a typical set of flight reconnaissance patterns, flown over a period of three days. Ice conditions are updated through these data daily. In addition, the IIP updates ice positions by using a computer model of ice movement and deterioration. Ice reports specifying the limits of all known ice are broadcast twice daily from four radio stations in the United States and Canada. Facsimile broadcasts of sea ice and icebergs are made once a day from the Boston station.\*

Canada's Ice Central is active throughout the year, but its efforts shift to the arctic regions in summer and early fall. From December through June, Ice Central surveys the Gulf of St. Lawrence-Belle Isle area with, on average, three visual reconnaissance flights per week. This information, combined with ship sightings and IIP information, is incorporated in a daily update of ice conditions. Facsimile broadcasts and ice reports specifying the limit of ice are issued twice daily nationwide via four radio stations. Ships in the St. Lawrence area receive information from the Halifax station. Halifax radio's facsimile broadcasts are hampered by a low quality fax broadcaster.\*\*

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\* Communication with Cmdr. Albert Super, USCG, July 1976.

\*\* Communication with Bill Markham, AES Ice Central, July 1976.

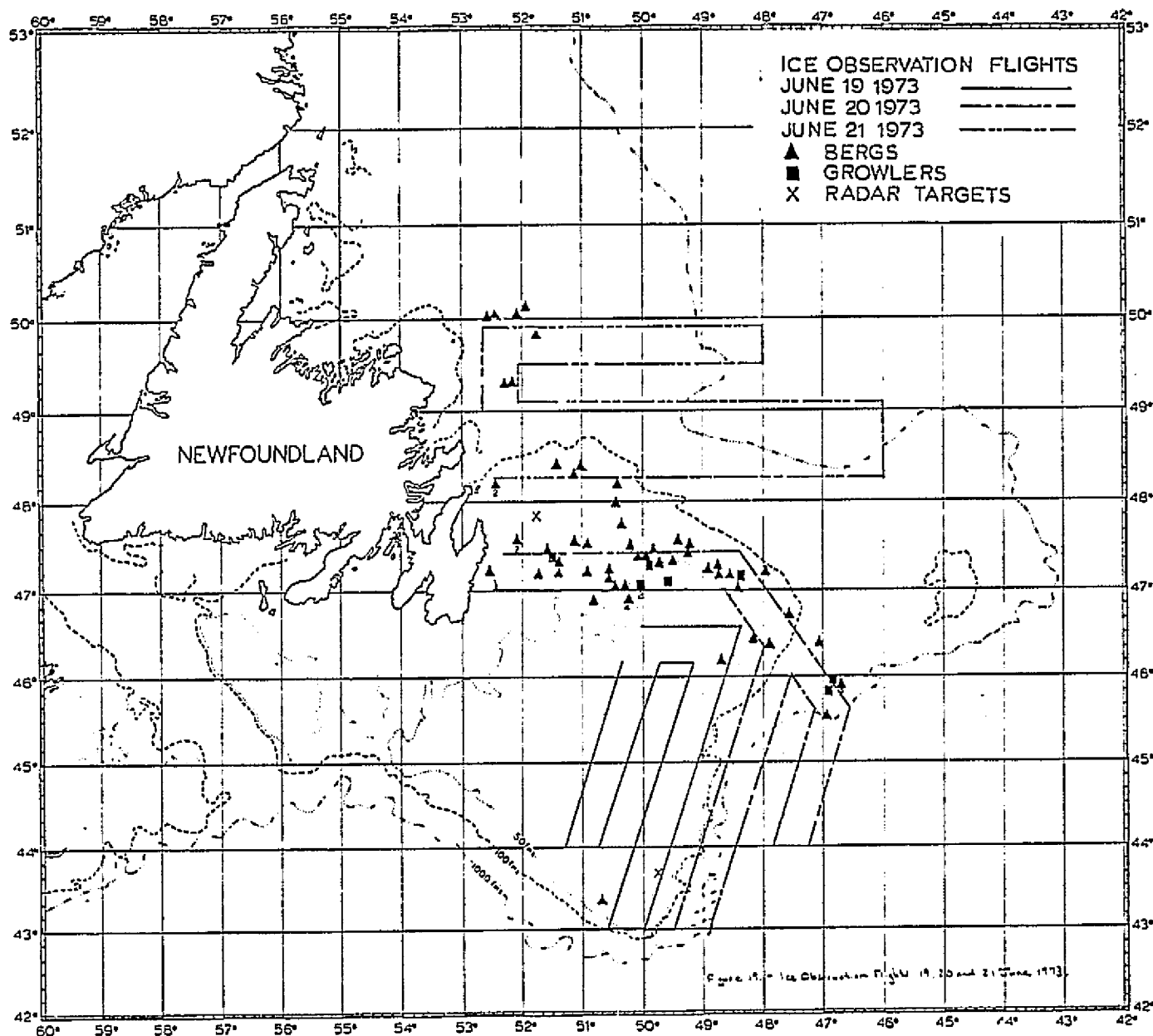


Figure 4.6 Typical IIP Surveillance Flight Patterns

\* USCG: Report of the International Ice Patrol Service in the North Atlantic Ocean, 1973. Bulletin No. 59.

Broadcasts of ice conditions in the Gulf of St. Lawrence and Cabot and Belle Isle Straits influence the choice of route for ships entering and leaving the St. Lawrence River. The captain must decide during the voyage which strait his ship will use, or the shipowners may give specific route orders to him. In either case, these decisions are affected by the quality of ice information received. A lack of adequate ice information can result in route selections that are indirect and/or dangerous. Decision makers choosing an exiting or entering strait during the transition months (May, June, July, August) face a lack of adequate ice information. The Belle Isle Strait is under intensive visual surveillance (three flights/week) only during May and June. After June the Canadians divert the aircraft to arctic operations.

Aerial reconnaissance efforts are hampered by fog and bad weather. Even aircraft with "all weather" sensors are ineffective when weather conditions prohibit takeoff. These conditions cause a 50 percent down time for Canadian surveillance efforts. Yet periods of bad weather are most critical to the shipping decision makers, since winds are strongest and ice is most mobile during storm conditions.

The operational SEASAT system will alleviate these difficulties, providing all-year and all-weather ice detection capability for all areas within receiving range of the Shoe Cove Station. This area is illustrated in Figure 4.7. SEASAT information, at least in the short-run, will not supplant but rather supplement current data collection efforts. SEASAT-A will not provide complete daily microwave radiometer and synthetic aperture radar coverage of the area of interest, but the information provided by the sensors will be significant. Typical

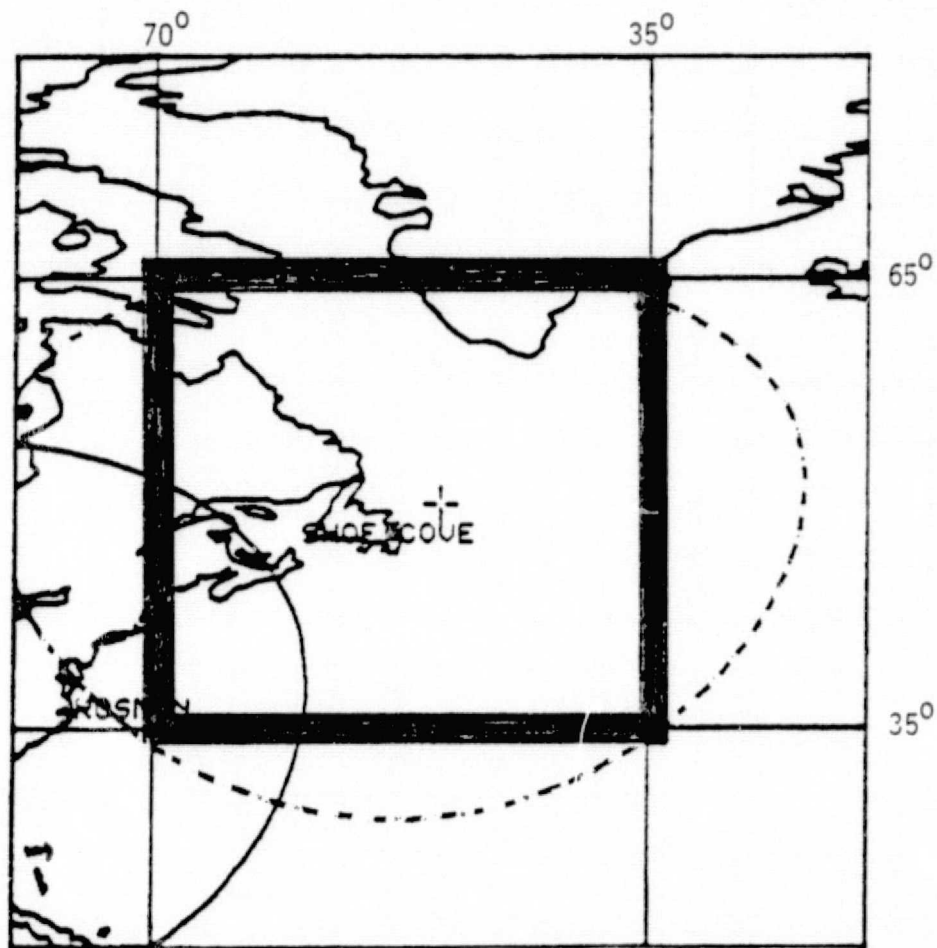
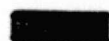
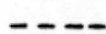


Figure 4.7 Shoe Cove Reception for St. Lawrence Area\*

KEY



Area of Interest



Shoe Cove Reception Limits

\* Interactive Graphics Orbit Selection (IGOS), Battelle Laboratories, Columbus, Ohio.



microwave radiometer and synthetic aperture radar coverage for two consecutive days are illustrated in Figures 4.8 and 4.9 respectively.

#### 4.2.2.4 Purpose

SEASAT's microwave radiometer and synthetic aperture radar sensors can provide additional sea ice and iceberg information for the St. Lawrence--Belle Isle area. The purpose of this Belle Isle Strait experiment would be to determine the worth of this added information in making better choice-of-strait decisions. Improvements in routing efficiency would be verified through an operational model involving real satellite information, ships and decisions. The operational model should also verify that the new information provided by SEASAT can be analyzed, distributed and used effectively.

#### 4.2.2.5 Description

The experiment would be conducted during May, June, July and August of 1978, assuming a prior successful launch of SEASAT-A. During this period, Belle Isle Strait becomes navigable and gradually ice free. The number and tonnage of European traffic using both straits would be monitored through reports to the Vessel Traffic Management center in Halifax and through the records of ship routing companies. Routing behavior for experimental and control groups would be compared to determine the improvements in routing due to the added information. Benefits under conditions of added information may accrue in three ways:\*

- Transit time savings,
- Fuel savings, and

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\* These benefits will be observed directly for a subset of the experimental group, and inferred by route choice for the remainder of the experimental group. See Sample Description, Section 4.2.2.6.

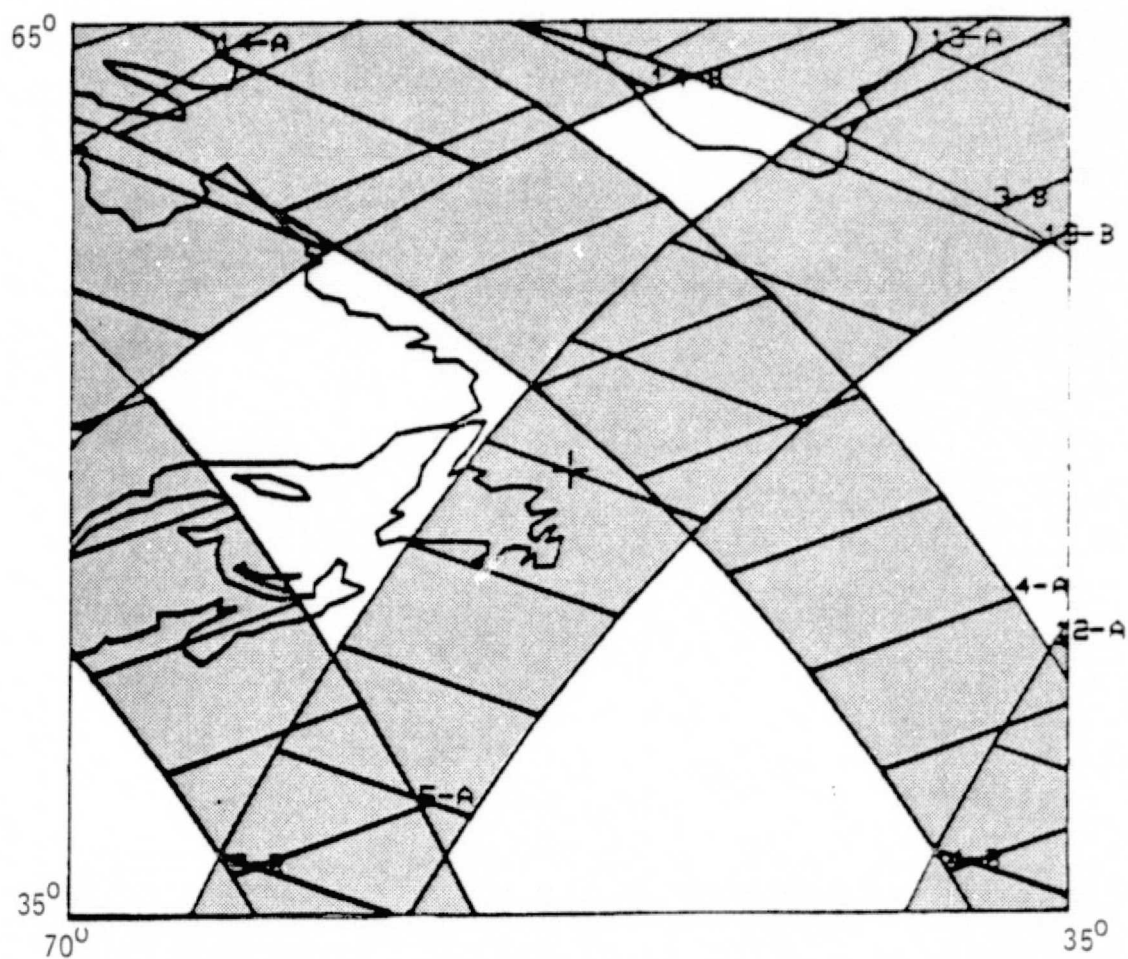


Figure 4.8 Typical One Day Coverage for SEASAT-A Microwave Radiometer Sensor\*

\*IGOS, Battelle Laboratories, Columbus, Ohio.

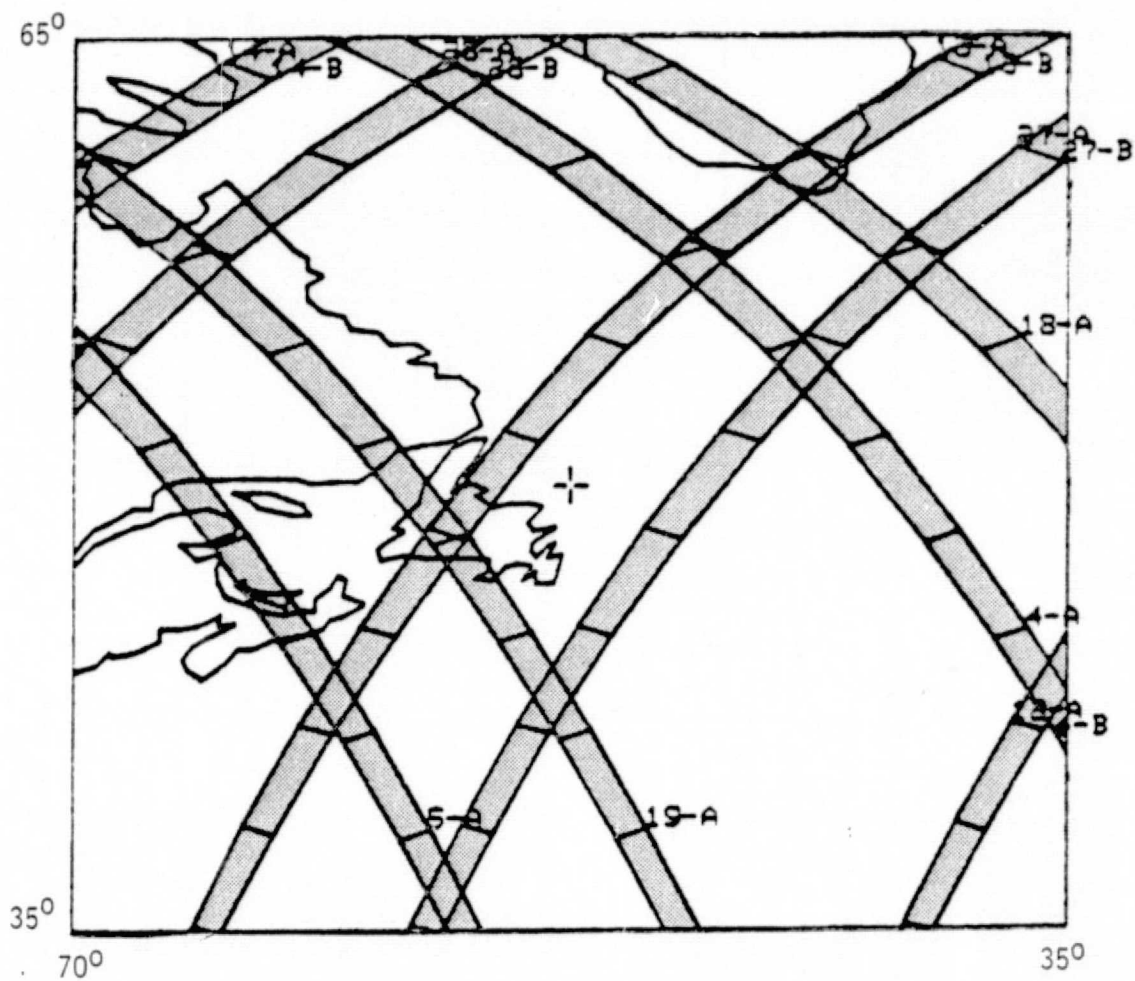


Figure 4.9 Typical Two Day Coverage for SEASAT-A Synthetic Aperture Radar Sensor\*

\* IGOS, Battelle Laboratories, Columbus, Ohio.

- Reduced loss of life and/or reduced vessel damage.

Dollar estimates of the benefits to the experimental sample would then be generalized to cover all European traffic for the period of interest. Belle Isle Strait routing benefits that might accrue to European shipping traffic during the remainder of the year are expected to be small relative to the benefits of added information during the transition period described earlier.

#### 4.2.2.6 Sample Description

The population under consideration consists of all vessel crossings between Northern Europe and the St. Lawrence Seaway for the months of May through August of 1978. Since the new SEASAT-A information will be made available to all traffic, the experimental group and the total population are one and the same.

The experimental group sample will consist of all such trips that report their choice of strait to Vessel Traffic Management in Halifax. It is expected that the experimental sample group will make up a majority of the population.

Since the entire population falls in the experimental group, a historical control group must be constructed. This proxy will consist of historical data for a representative subgroup of ships whose trips fall in the experimental sample. The historical data will be taken for a preceding year which exhibits ice and weather conditions similar to those of 1978.

This subgroup will also be used to form a proxy for a second experimental sample, since it may be the case that a short-run lack of user confidence in new SEASAT-A data will cause an underestimate of the

long-run routing benefits of SEASAT-A. Shippers may well be reluctant to rely on new, untested data sources. Therefore, a panel of routing experts will examine the ice and weather situations faced in 1978 by the subgroup mentioned above, and determine any changes in routing that would be made if the SEASAT-A data were assumed to be fully reliable.

A visual representation of the control, experimental and second experimental samples is given in Figure 4.10. The design uses direct observations, expert opinion and statistical inference to determine vessel routing decisions. The control, experimental and second experimental samples are used to hypothesize the makeup of the total population of Control, Experimental 1 and Experimental 2 groups.

#### 4.2.2.7 Analysis

In order to describe the calculation of economic benefits, it is necessary to index the three cases of interest.

0 = No SEASAT Data (Control Group)

1 = SEASAT-A Data Provided (Experimental Group 1)

2 = SEASAT-A Data Fully Accepted (Experimental Group 2)

For each case, we desire an estimate of the number of trips (by weight class) that would pass through the Belle Isle Strait. Let  $n_{1j}$  be the number of trips in group 1 of weight class  $j$  that choose the Belle Isle Strait. Then, for example,  $n_{1j} - n_{0j}$  estimates the additional number of ships using the Belle Isle Strait when SEASAT-A data is provided. We can then examine three types of benefits.

$T_j$ : dollar value of time saved per Belle Isle trip (weight class  $j$ )

$F_j$ : dollar value of fuel saved per Belle Isle trip (weight class  $j$ )

Key: — Direct Observation  
 ~~~~~ Expert Opinion  
 ----- Inference

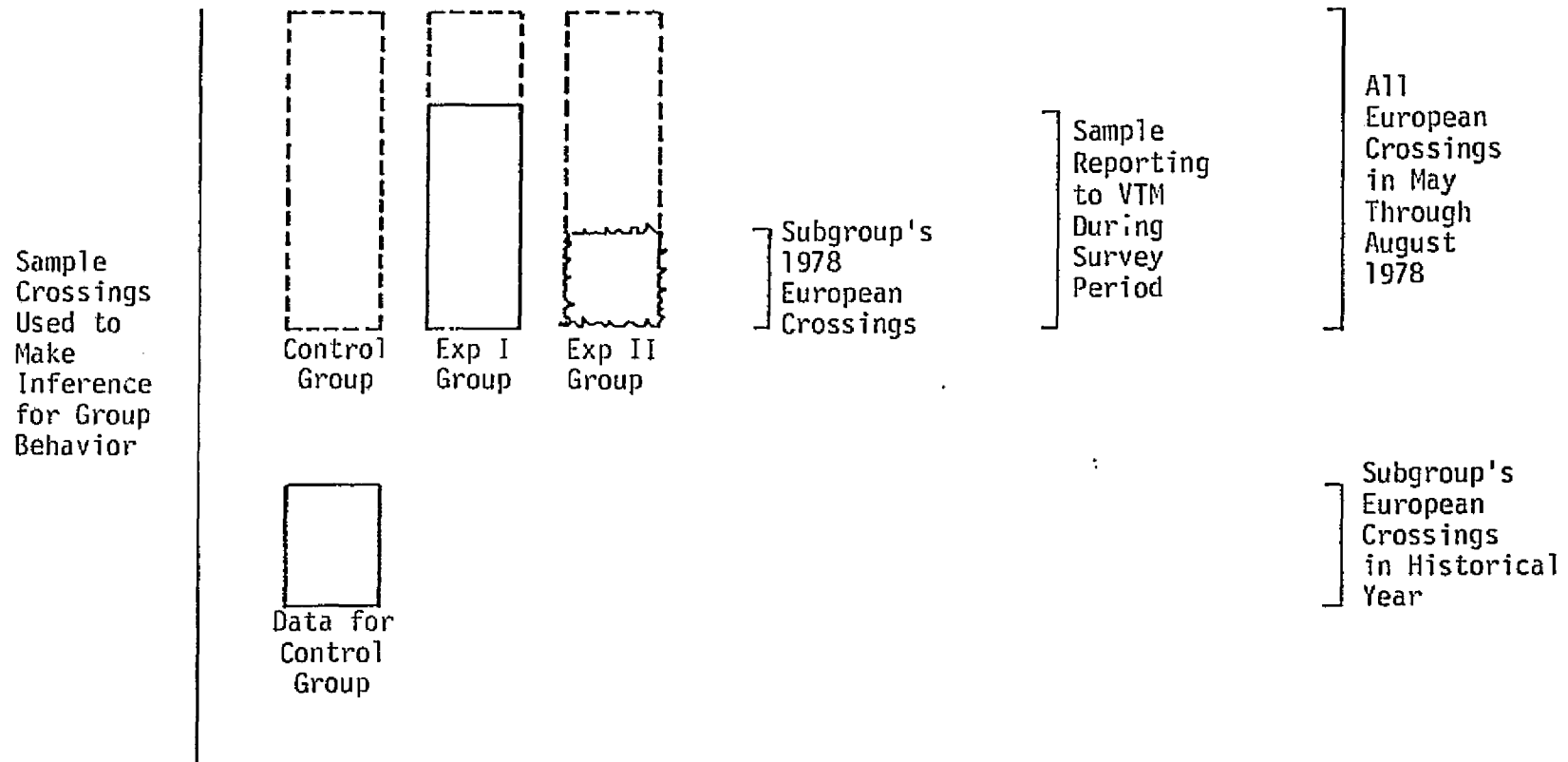


Figure 4.10 Characteristics of Control and Experimental Groups

$H_j$ : dollar value of hazards reduced per Belle Isle trip  
(weight class  $j$ )

Sources for these data are outlined as follows:

$T_j$ : Estimated from historical data or expert opinion

$F_j$ : Estimated from historical data or expert opinion

$H_j$ : Estimated from historical data or expert opinion

$n_{0j}$ : Statistical inference based on percentage of ships in  
weight class  $j$  using Belle Isle in the historical sample

$n_{1j}$ : Statistical inference based on percentage of ships in  
weight class  $j$  using Belle Isle during the 1978 season

$n_{2j}$ : Statistical inference based on percentage of ships in  
weight class  $j$  hypothesized to use Belle Isle in 1978  
if the decision maker accepts SEASAT data as reliable.

By multiplying dollar savings per additional Belle Isle  
route times the total number of additional Belle Isle routes, we find  
the total dollar benefits in each of the three categories. For example:

$$\begin{array}{l} \text{Dollar benefits for 1978} \\ \text{for fuel savings based} \\ \text{on actual SEASAT informa-} \\ \text{tion use (Experimental} \\ \text{Group 1)} \end{array} = \sum_{\substack{\text{weight} \\ \text{class} \\ j}} F_j (n_{1j} - n_{0j})$$

and

$$\begin{array}{l} \text{Dollar benefits for 1978} \\ \text{for fuel savings based} \\ \text{on complete SEASAT infor-} \\ \text{mation use (Experimental} \\ \text{Group 2)} \end{array} = \sum_{\substack{\text{weight} \\ \text{class} \\ j}} F_j (n_{2j} - n_{0j})$$

This analysis then, will yield estimates of one year benefits  
in time, fuel and hazard savings due to the added information provided  
by SEASAT-A. The analysis will also provide an estimate of the degree  
of confidence placed in the new data source by ship routing decision  
makers. Furthermore, it may be possible to estimate the magnitude of

the heretofore unknown (but positive) correlation between SEASAT-A benefits and the benefits to be expected under a fully operational system. The three satellite operational system would provide complete SAR and MR coverage at least twice a day (cf. pp. 10-11), and would allow reliable 48 hour forecasts of ice and weather conditions.\* The panel of routing experts consulted in the formation of the second experimental sample will also be asked to determine additional routing changes that would occur due to added information from a fully operational SEASAT System. The expected benefits would then be calculated as outlined above.

A breakdown of responsibilities associated with this experiment by participating organizations is shown in Table 4.2.

#### 4.2.3 A Tanker Routing Experiment in the Agulhas Current

The Agulhas Current sweeps down South Africa's southeast coast moved by its own momentum and the dynamic forces acting in this part of the ocean. It has its origin in the trade wind area of the Central Indian Ocean where the surface drift is known as the South Equatorial Current. This drift current impinges on the east coast of Madagascar and the coast of Mozambique, forming two stream currents, one flowing southwards down the coast of Madagascar and the other along the Mozambique coast. The Madagascar section on reaching the southern extremity of the island veers across the Mozambique Channel towards the coast of South Africa at Natal where it meets the Mozambique Current between Durnford Point and Durban and then flows southwards as an oceanic river, the Agulhas Current.

The course of this river is greatly influenced by the submarine topography due to the depth to which the core of the current

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\* SEASAT Economic Assessment, Volume II, ECON, Inc., 1976.



| Table 4.2 Responsibilities                                        |                                                     |                                                         |                 |         |         |                      |
|-------------------------------------------------------------------|-----------------------------------------------------|---------------------------------------------------------|-----------------|---------|---------|----------------------|
| Group                                                             | Economic<br>Verification<br>Program<br>Coordination | SEASAT-A<br>Information<br>Analysis and<br>Distribution | Data Collection |         |         | Economic<br>Analysis |
|                                                                   |                                                     |                                                         | Group 0         | Group 1 | Group 2 |                      |
| ECON                                                              | X                                                   |                                                         |                 |         |         | X                    |
| AES Ice Central<br>(Canada)                                       |                                                     | X                                                       |                 |         |         |                      |
| USCG International<br>Ice Patrol                                  |                                                     | X                                                       |                 |         |         |                      |
| Canada Centre for<br>Remote Sensing                               |                                                     | X                                                       |                 |         |         |                      |
| Canadian Coast<br>Guard Vessel Traf-<br>fic Management<br>Halifax |                                                     | X                                                       |                 | X       |         |                      |
| Marine Traffic Reg-<br>ulation Center,<br>Quebec                  |                                                     |                                                         |                 | X       |         |                      |
| Statistics Canada                                                 |                                                     |                                                         | X               | X       |         |                      |
| Commercial Ship Routing<br>Companies                              |                                                     |                                                         | X               | X       | X       |                      |

penetrates, i.e., over 1000 feet (330 m). Being deeper than the edge of the continental shelf, and because the shelf slope is so steep in this area between Durban and East London, the main core of the current is, generally speaking, confined to the seaward side of the continental shelf. Being a western boundary current, it attains its maximum velocity just seawards of this shelf edge, where speeds of 4 to 5 knots are experienced between Port St. Johns and East London. This is especially true during the southern summer and autumn where the NE Monsoon is blowing in the Arabian Sea, ensuring a maximum flow through the Mozambique Channel. The width of the Agulhas Current is from 60 to 100 miles (95 to 160 km). Under certain circumstances the southerly flow extends across the continental shelf to the coast.

This current is then in the midst of the supertanker\* routes to and from the Persian Gulf and Caribbean and Euro-ports. When steaming north, empty ships try to avoid the main flow while laden ships steaming south try to sail in its main force. Identifying the boundaries of the current would be analogous to the work NOAA is now doing in defining the boundaries of the Gulf Stream using the VHRR's IR data from NOAA-3, 4, and 5. SEASAT A, using the V & IR's IR data, should be able to locate the boundaries of the current to the order of 5 kilometers. An improved V & IR instrument could do even better. In addition, the SAR could also identify the current boundaries because of the difference in roughness in and out of the current.

In addition to the location of the current, information on winds--speed and direction--and wave heights would be of value in

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\*Smaller tankers are once again using the Suez Canal.

forecasting most likely times of potential "abnormal"\* waves traveling in the current. This information coming from the Microwave Radiometer, Scatterometer, altimeter and possibly the SAR, when combined with meteorological information, would provide the necessary data for abnormal wave forecasting.

Location of the current would probably best be done by NOAA. They now do the Gulf Stream. They then could pass this information as they now pass the Gulf Stream information to ship routers and/or tanker captains.

The information needed to forecast times of abnormal waves might best be handled through FNWC or NWS. Ship routers and/or tanker captains could then make use of this information.

#### 4.3 Applications to the Ocean Fishing Industry

##### 4.3.1 A Tuna Fisheries Experiment

The collection of tunas has long been associated with sea temperatures. The tuna schools are usually found at or near the boundaries between warm and cool water. The sensitivity is in the order of a few tenths of a degree Celsius. The location of these areas involves searching and hit or miss techniques by the tuna boat captains. Operation costs average about \$3,000 a day. Any system that can accurately pinpoint these temperature areas will save time and monies.

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\*An abnormal wave is defined as one in excess of 18 meters and preceded by a long deep nonsinusoidal trough.

This experiment proposes the use of SEASAT-A IR and SMMR data to generate maps of the Pacific with isotherms. These maps preferably should have the best temperature resolution available from SEASAT-A. (0.2 to 0.5°C is preferred but the SEASAT-A instruments are not expected to achieve this accuracy.) Resolutions of 10 km with spatial grids of 100 km are desired. Since the fishing areas are known to have 40 to 80 percent cloud coverage, the more accurate IR data will have to be supplemented by microwave information.

Most large fishing boats have facsimile machines and, therefore, these maps should be sized for facsimile transmittal. Eighteen-hour coverage is desired, but 36-hour coverage is the best achievable for SEASAT-A.

Sea state and wind conditions also can be detrimental to efficient collection of fish. These maps should also contain wind speed and direction as well as sea (wave height) state.

Learning periods for the tuna boat captains is estimated to be from one to six months. Therefore, these maps should be supplied for the lifetime of SEASAT-A.

#### 4.3.2 Alaskan Crab Fisheries Experiment

The best crab collection is done near the ice line. The breakup of the ice, and the movement of the ice is of prime interest to the crab fisheries. This information can be obtained from the visual and infrared instrument and the imaging radar.

#### 4.3.3 Fish Yield Forecasts Tied to Surface Water Transport

The shrimp and menhaden fisheries in the Gulf of Mexico and the California anchoveta fishery in the Pacific are greatly influenced

by the surface transport of eggs and larvae into areas of high growth potential (nutrients, temperature, and turbidity factors). Data on the areas of high growth potential and on the local water surface layer motions over significant lengths of time are important to improved management of these important marine resources.

SEASAT has the potential to provide all-weather temperatures, wind or surface shear fields, and current boundaries relative to the above descriptive needs. In addition, Nimbus G can provide colorimetry to establish chlorophyll and turbidity effects and Tiros-N can provide improved surface resolution with clear weather temperatures. The synergistic effects of these three data sources are important to demonstrating capability and designing an operational demonstration. An initial activity is presently underway with NMFS and NASA funds to demonstrate the ability of a tower mounted scatterometer to measure surface wind shear and surface transport. Initial efforts to demonstrate the wind shear measure are to be undertaken off the California coastline in conjunction with a larger SEASAT-A ground truth program. It is expected that in the following year the surface transport experiment will be moved to the Gulf where the available towers are taller and farther out from the shore. A demonstration program will then be undertaken to operationally incorporate SEASAT-A wind shear data into a surface transport forecasting model in each of the areas. Incorporation of temperature and nutrient data from the three-satellite synergism would provide a valuable adjunct.

Participants in this effort would include the commercial shrimp, menhaden, and possibly limited California anchovy fisheries, the National Fisheries Engineering Laboratory, the Southeast and Southwest Fisheries Centers, JPL, GSFC, and several universities.

#### 4.3.4 Marine Fisheries Upwelling Forecasts

There are two major U.S. fisheries areas with identified interest in upwelling forecasts. The Peruvian anchoveta yield is strongly linked to upwelling. NMFS has suggested an El Nino watch, to monitor upwelling conditions and to forecast future variations. Many coastal fisheries from northern California to the Aleutians also rely on coastal upwelling processes. An operational upwelling forecasting capability for this fishery is provided by the NMFS, Pacific Environmental Group.

Upwelling areas can be identified by temperature effects, colorimetry due to the presence of chlorophyll or turbidity, and modulations in the surface motions due to the local source. SEASAT is expected to provide all-weather temperature (particularly useful for the North American coastal upwellings) of appropriate accuracy which can be processed to predict upwelling areas. In addition, the Nimbus-G Coastal Zone Color Scanner and the Tiros-N AVHRR for clear weather temperature would make important synergistic contributions. Aircraft flights are needed over these areas to determine the synergistic detectability limits in these sensors. A three-satellite demonstration could then be planned for FY 79 in which satellite, aircraft and ship data are collected simultaneously to demonstrate the satellite

measurement feasibilities and to provide a pilot demonstration of forecast capability.

Participants in this effort would include JPL and GSFC in sensor interpretation, the National Fisheries Engineering Laboratory and the Southwest and Northwest Fisheries Centers, and the commercial fisheries in the two areas. Particular effort will be made to demonstrate direct benefit to individual fisheries.

#### 4.4 Ice Monitoring Applications

##### 4.4.1 Application to the International Ice Patrol

The U.S. Coast Guard International Ice Patrol is involved in a mission to predict iceberg drift and deterioration rates in the vicinity of the Grand Banks of Newfoundland. These predictions are formulated into ice predictions for use by the marine transportation interests utilizing the shipping lanes in the northwest Atlantic.

At the present time, data are collected by three or four oceanographic cruises in the spring and early summer. Currents computed from these data reflect only the internal distribution of mass and rely on an assumed level of no motion. True measurements of ocean topography would not require assumptions of no motion and would therefore reflect the true current field more accurately. Using the combined data from SEASAT-A and from ships, the relative contributions of tides, wind driven and geostrophic currents can be evaluated. SEASAT-A would enable the coverage of a larger area on a more timely basis than is now possible with oceanographic cruises.

The proposed experiment envisions providing the International Ice Patrol data relative to sea surface topography and surface temperature

in order to develop current and temperature fields respectively. SEASAT-A surveys of icebergs off northeastern Newfoundland, the coast of Labrador, and northward into Baffin Bay will aid in determining iceberg severity potential prior to and during each ice season. These data will be provided by the SEASAT-A altimeter, SMMR, SAR, and VIS&R instruments.

The proposed data on currents and sea surface temperature would enable the International Ice Patrol to provide more comprehensive and timely information on iceberg drift and deterioration to ships in the North Atlantic.

#### 4.4.2 Application to Great Lakes Ice Monitoring

Marine transportation interests operating within the Great Lakes require information and forecasts relative to ice conditions during the winter months. Timely data concerning ice concentration, thickness, and lead patterns would allow the development of nowcasts and forecasts which could extend the navigable shipping season a month or so on the Great Lakes during the ice season.

The proposed experiment would involve providing data from the SAR, SMMR, SCAT, and VIS&IR instruments on SEASAT-A on a near daily basis to the Coast Guard and selected shipping interests in order to develop improved ice condition information for the Great Lakes.

#### 4.4.3 Monitoring Alaskan Sea Ice

Marine transportation activities operating in the Alaskan Sea region providing logistics support and supplies to oil operations



along the North Slope are in need of accurate ice forecasts in order to maximize seasonal operations.

In order to develop forecasts of use to the shipping interests, it is necessary to obtain information relative to ice drift and pack deformation, as well as on the general geometry of the floes and leads. In addition, data relative to the state of divergence (increasing or decreasing) of the ice pack is required.

The proposed experiment involves providing Coast Guard and selected forecasting services with ice data derived from the SEASAT-A SAR, SMMR, SCAT, and VIS&IR instruments on a near daily basis. Ice forecasts for the Alaskan area, including the Beaufort and Bearing Seas, will be developed and utilized in optimizing North Slope oil marine transportation operations over the course of one or two winter seasons.

#### 4.5 Coastal Zone Applications

##### 4.5.1 Southeast and East Coast Hurricane Wind and Landfall Forecasts

###### 4.5.1.1 Introduction

SEASAT data is assumed to contribute to improvements in the prediction of parameters which quantitatively describe sea and weather phenomena destructive to the coastal zones of the United States.

Economic benefits attributable to SEASAT's new data then result from reductions of losses, as a consequence of improved prediction, for destructive phenomena that occur in coastal zones. The benefits are then constituted from avoidable losses.

In the SEASAT Economic Assessment benefits were derived from three distinct sources:

1. Direct action of sea incursion on property
2. Reduced expense for hurricane emergency procedures
3. Direct modification (seeding) of hurricane power.

Benefits from the effect of sea incursion on property require preventive action to be taken, either through control of the transient predicted sea phenomena or through some form of human cooperation which seeks to safeguard the property. Improved prediction relating to sea incursion phenomena requires an integration of many individual computer models to be successful, a condition judged unlikely to occur before 1985.

Reduced expenditures associated with hurricane emergency procedures and therefore the benefits of source (2.) are a result of improved prediction of hurricane landfall, most specifically that of landfall predicted position with a confidence accepted by affected populations. This advance in prediction capability will result, not only from improved data or more extensive data, but from improved physical and analytical hurricane modelling in concert with an increase in available computer power. As such, this benefit is likely to be slowly accumulated over possibly the next twenty-five years.

The last source of economic benefit will result from a successful, combined attack, both theoretical and experimental, on the techniques for seeding hurricanes. It was conjectured that SEASAT data would contribute to the establishment of an operational technique of seeding control. At present this particular potential source of

benefits is being developed under Project Stormfury, currently in a constrained manner because of guarantees sought by the Japanese government, against enhanced precipitation as a result of typhoon seeding.

Defining and constructing a meaningful, unequivocal quantifiable Economic Verification Experiment (EVE) of SEASAT-A benefits to the U.S. coastal zones is clearly difficult. Of the three benefit sources investigated, the one relating to improved landfall prediction seems most promising for a SEASAT-A experiment, and an experiment is proposed for this phenomenon.

#### 4.5.1.2 The SEASAT Satellite

SEASAT-A is a user demonstration version of SEASAT planned for launch in the first quarter of CY 1978. It is intended to provide a sampling of data by which users can evaluate the utility of SEASAT, and also to allow users to specify the nature of the data of most use to them for an operational version of SEASAT.

The SEASAT-A instrumentation will consist of a pulsed microwave radio altimeter, a scatterometer, an imaging radar, a microwave radiometer and a visual and infrared radiometer all operating continually, except for the imaging radar which will operate on real time readout only.

The SEASAT data will be pertinent both to the sea surface topography and to the physical parameters of the sea surface.

SEASAT-A will be launched into a circular orbit, with an altitude of 800 km, an orbital inclination of  $108^{\circ}$  and an orbital period of 100 minutes. Earth surface coverage will be completed once every 36 hours.

#### 4.5.1.3 Benefit Experiment Evaluation

A benefit experiment evaluation for SEASAT-A must allow a measurement or quantification of the benefit contribution resulting from SEASAT-A data only. In the majority of application cases an incremental cost will be incurred also, associated with the processing or reduction of the derived data. In the most general data application case some of this incremental cost will be allocatable to the satellite and the remainder will be a user cost.

SEASAT-A data will, it is assumed, improve the accuracy of prediction of coastal zone damage phenomena parameters, such as the time of occurrence, the duration of occurrence, the extent of occurrence, or the positional location of occurrence, of some of the phenomena which would result in damage or destruction to property.

Coastal zone damage results from the interaction between transient, excessive or unexpected sea condition and weather activity and property in the land/water areas in the coastal zones. The phenomena of concern can all be currently forecasted or predicted by some existing techniques. The data supplied through SEASAT will incrementally improve, it is assumed, these current forecasts. The evaluation experiments must therefore always allow measurement to be made of the difference between forecasts with and without SEASAT data. In some instances it is to be expected that these differences may be very small. This raises the evident problem: If current techniques are applied in each case of measurement, then the 'noise' in the technique may obscure the contribution of the SEASAT data. At this stage, however, in general, current

techniques will be the principal methods for evaluation, even though the advent of SEASAT data may seriously question the validity of a current measurement technique.

In a general sense a benefit experiment evaluation will result in a benefit measure which has an associated frequency of occurrence or probability of occurrence distribution. This is a consequence of dealing with completely uncontrolled natural phenomena. Thus, before anything can really be stated about benefits, enough sample events must have been evaluated for a benefit to be defined with a level of confidence. This defines a benefit as being clearly a consequence of the availability of the new data supplied and not simply a consequence of chance in the technique of measurement. For phenomena associated with coastal zone benefits this may require many years of direct evaluation because of the infrequency of natural occurrence of the phenomena being evaluated. This limitation can be obviated if the experiment can be supported by a simulation of the new data. This implies the availability of the distributions of all newly provided data.

In the coastal zones, the naturally occurring phenomena of interest create incremental costs for the population in residence in the coastal zones and for the population with real interests in the coastal zones. These incremental costs, which are a direct result of the destructive phenomena, are conceptually subdivided into two categories. One category contains what are considered to be avoidable incremental costs, the other category contains unavoidable incremental costs. The category of avoidable costs contains all those costs that would be eliminated if the prediction of the phenomena of interest was

perfect and if all requisite actions were implemented to then eliminate the occurrence of these avoidable costs. Improved prediction should result in incremental avoidable costs or benefits but still requires all requisite actions to be taken to reduce the avoidable costs, even though the prediction will be imperfect.

In an experimental evaluation of benefits, the occurrence of a destructive phenomenon above the damage threshold in the coastal zones should result in some damage. If the damage can be considered to be the source of an avoidable cost then prediction would have reduced it, assuming appropriate action was taken. In practice, however, the definition of both the threshold and the safeguarding action can be extremely difficult to select with reasonable precision so that the consequent benefit can be clearly allocated to SEASAT-A data.

Ideally, in constructing an evaluative experiment two or more identical real interests, such as a vessel, should be exposed to identical damaging phenomena. At least one of the real interests should, however, based on prediction improvement, be safeguarded differently. Then the damage difference resulting from different methods of safeguarding would indicate the benefit distribution.

However, large-scale natural phenomena do not lend themselves easily to such logical constructions of experiments of this type. Damage results in general from a wide variety of quasi-random events that proceed from the interactions between phenomena and real interest. For example, a small-craft warning seems to be a forecast that is understood, yet it is not a precise statement because there is no definition of

what constitutes a small craft. In essence, the level of known detail for damage relationships from natural phenomena is very limited. A small-craft warning is, in practice, a doctrinal description, the response to which is largely a function of judgement based on experience and knowledge of his craft by the master of the craft.

Evidently, in a practical sense, where prediction improvement is available, the owner of a real interest in the coastal zone, aware of risk, must also be convinced that the cost of following recommended safeguarding procedures will be less than the total costs of the damage expected if safeguarding procedures are not followed. Generally, a real interest owner covers his contingencies by appropriate insurance, and the application rules of insurance could be instrumental in generating compliance with safeguarding procedures.

This discussion on experiment construction identifies some of the difficulties involved in determining experimentally benefits to property losses from tropical cyclones, extratropical storms, tsunamis and surf.

Hurricane seeding benefits, at this time, have to be viewed as being unobtainable. The basic seeding objective is to reduce the available latent heat in a hurricane and as a consequence to reduce the attained wind velocities. However, some experts conjecture that a result from seeding may be that while the winds are reduced, the precipitation is increased, although such an exchange has not been experimentally observed. If this should occur concern could be expressed by those for whom the disbenefit from precipitation exceeds the benefit from wind reduction, which depends on the context of the hurricane or typhoon.

As a consequence it has been decided to consider an experiment in which landfall prediction or position prediction of a hurricane may be improved. Practical benefit could be derived from any inferred position prediction improvement.

Because Project Stormfury seemed to be concentrating its efforts on the eleven or so typhoons expected to arise in the Pacific each year, and to tracking them with and without seeding in a northwesterly direction from Guam, it seemed reasonable to consider introducing SEASAT-A data into this program. However, it now appears that Project Stormfury will be considerably curtailed and it is proposed to consider an experiment on hurricanes in cooperation with the National Weather Service.

#### 4.5.1.4 The Proposed Coastal Zone Experiment with SEASAT-A DATA

The National Weather Service currently has a technique of prediction of hurricane phenomena, used in each hurricane season, to predict appropriate parameters including landfall. While prediction techniques may change during the period 1978-1981, during which SEASAT-A data is expected to be available, it is proposed to conduct the following non-real time experiment in cooperation with and coordinated by Dr. John A. Brown, Jr., Chief Development Division, National Meteorological Center, N.W.S., NOAA, World Weather Building, Washington, D.C. 20232 (301-763-8005), to determine the improvement in hurricane landfall prediction produced by SEASAT-A data.

1. During the time period that appropriate data will be supplied by SEASAT-A, that data will be made available to Dr. John A. Brown, Jr.



2. His group will scrutinize the data supplied to assure himself of its appropriateness for incorporation into the operational hurricane prediction models.
3. NASA will be informed if the data is considered to be inappropriate by Dr. Brown.
4. If the data is appropriate Dr. Brown will incorporate the SEASAT-A data into his hurricane models as required to produce hurricane landfall predictions.
5. The SEASAT-A data will be incorporated in a non-real time manner.
6. Landfall prediction results will be produced for the techniques then in use (without SEASAT). Predictions will then be made using the same techniques with SEASAT data appropriately incorporated.
7. The landfall prediction results with and without SEASAT data will then be compared to ground truth for every appropriate hurricane during the time period of SEASAT-A data supply.
8. Whenever possible, for hurricanes that do not landfall, positional tracking prediction will be made and separate results will be provided to infer landfall prediction variations with and without SEASAT data.
9. Since it is expected that during the three-year life of SEASAT-A only about six hurricanes will landfall on the U.S. Gulf and Atlantic coasts, it is suggested that if possible Dr. Brown estimate or determine the sensitivity of landfall predictions to SEASAT-A data quality.

#### 4.5.1.5 Derivation of Economic Benefits

Avoidable economic losses are assumed to exist because the hurricane interaction area is too large as a result of inadequate prediction of the hurricane landfall position. The area warned must then include the overwarned area, because of this landfall position prediction error. Reducing this prediction error will then reduce the overwarned area, reducing the associated avoidable economic loss, which produces a benefit.

The costs  $C$  of warning an area  $A$  are assumed to be dependent on the population density  $P$  in that area. Thus

$$C = APc$$

where  $c$  is the warning cost per unit of population. If within the area  $A$  is another area,  $a$ , which is the overwarned area, then the avoidable cost  $D$  of overwarning is similarly

$$D = aPc$$

If further, as a consequence of improved prediction, there is a fractional reduction in the overwarned area by an amount  $f$ , while at the same time the population density changes by a ratio  $p$ , then the avoidable cost that is avoided or the benefit  $B$  is given by

$$B = fapPc = fpD$$

The value of  $f$  will be provided by the experiment as a consequence of SEASAT-A data. This value will be assumed appropriate to all hurricane landfall predictions.

The value of  $p$  will be determined using projections based on population trends as defined by the U.S. Department of Commerce, to the time period of interest. The parameter,  $D$ , will be taken from a theoretical paper by Sugg.\*  $D$  is estimated as a range of values and

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\*Sugg, Arnold L., "Economic Aspects of Hurricanes", Monthly Weather Review, Vol. 95, No. 3, March 1967, pp. 143-146.

will be adjusted for inflationary trends to the time period of interest. Sugg's 1966 values for the average number of hurricane landfalls in the U.S. (1.5 per year) ranged from \$10.4 million to \$34.9 million. Using an inflation factor of 50 percent to 1975, the current range of overwarning costs is \$13 million to \$43.6 million in 1975 dollars.

The benefit formula in millions of 1975 dollars is then given as a range, attributable to SEASAT-A data, as

$$13fp \leq B \leq 43.6 fp$$

where the average number of hurricane landfalls is assumed to be constant up to the time period of interest.

It is expected that population density projections will provide a range of values also. Furthermore, it is expected that the values of  $f$  supplied by the experiment will have a range of statistical confidence values.

The benefits are therefore expected to be presented as a range of values with associated confidence levels.

#### 4.6 Other Experiments

##### 4.6.1 Marine Fisheries Surveillance of the 200-Mile Limit Using the SAR

Aircraft flight feasibility tests carried out cooperatively in the past year between NASA, the National Marine Fisheries Service of NOAA and the Coast Guard have demonstrated that an imaging radar can detect ships and locate them over a wide range of seas (smooth to 25 meter waves). Initial evaluation of the data also implies that there may be a capability to size the ship, to tell something about

the ship superstructure, to identify its direction of motion and to tell whether it is pulling certain kinds of nets. In the coming year these initial feasibility tests are to be expanded to provide more data pointed towards the last set of questions.

During SEASAT-A a system would be set up to provide radar images in real time to major fisheries activities in the Grand Banks and Alaska areas over a period of several months. These data would be evaluated for detection and identification capabilities in support of existing ship and airplane systems. Potential benefit areas are increased effectiveness or possible reduction in the planned expansion of the ship and airplane surveillance fleets. As the follow-on SEASAT missions develop this initial feasibility effort would be expanded to allow an operational demonstration, with the cost of operation gradually phasing into the Coast Guard budget.

This effort would last through about 1982 or until an operational quality system is implemented. Participants would include the Coast Guard, NASA, NMFS, and commercial fisheries.

#### 4.6.2 Marine Mammal Management

In general, it does not appear to be feasible to identify individual mammals or small groups of mammals through remote sensing from space. It does appear possible, though, to track individual mammals by attaching suitable transmitters on these mammals and inferring general migration patterns from the satellite relay link tracking of a few individuals. A prototype system for porpoise to be tested with Nimbus-G and TIROS-N, has been proposed cooperatively by NOAA, NASA, the Navy, the Marine Mammal Commission and the Porpoise

Rescue Foundation. Porpoise management has particular importance to the tuna industry while whales, seals, sealions, etc. are all considered somewhat endangered species. All four of these mammals are the responsibility of the National Marine Fisheries Service of NOAA.

In SEASAT this idea could be extended considerably in terms of the porpoise and seal populations. Porpoises especially and some seals tend to migrate in schools of 100 to 600. These schools modulate the water in their passage, especially in feeding, to such an extent that their area size is easily identifiable from aircraft photography. Because of this surface modulation it is expected that the SEASAT imaging radar will also see schools whose areal size is at least 25 meters.

During FY 78, imaging radar flights would be made over migrating and feeding porpoise schools and, if possible, migrating seal schools. These would be to establish the necessary identification characteristics and to infer a limit in detection. After SEASAT-A is launched, a program to obtain simultaneous satellite, aircraft, and ship observation would be undertaken and the data utilized to test operational feasibility. Future SEASAT missions are expected to have ground data relay-link capability which would allow a combination of the imaging and tracking technique.

This experiment would require semioperational SAR image processing in conjunction with follow-on SEASAT launches utilizing transmitting porpoises to initiate SAR operation with short-time data storage for peculiar areas. Participants would include NMFS, NASA, Interamerican Tropical Tuna Commission, Scripps Oceanographic Institute, and private tuna fishing companies.